CROWN BIOMASS RESPONSE
OF 7 YEAR OLD *PINUS RADIATA* D. DON
TO FERTILISATION AND THINNING

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ABSTRACT

Within-crown and total tree biomass of 7 year old Pinus radiata D. Don was followed for two years in response to thinning and N fertilisation in a 2^2 factorial. A non-destructive biomass estimation procedure is described whereby individual tree crown biomass components are predicted from total enumeration of branch diameters of sample trees and independently calculated regressions of biomass components on branch diameter. Estimates of regression coefficients from whole-tree biomass data and from branch data sampled from individual trees in the field are comprehensively analysed. Green crowns were stratified into zones for sampling and predictive purposes; the strata were biologically defined by year of branch initiation and branch cycle number. The effectiveness of crown stratification is evaluated. Non-destructively predicted foliar weights are compared with known weights to gauge accuracy and precision. Within-crown foliar biomass response was closely related to branch diameter response. Over bark volume increments were measured on the same trees for which foliar biomass estimates were made. Annual volume response 1 year after treatment was successfully predicted as a function of tree foliar weight and foliar efficiency. Mean tree volume increment (1978-1979), of the fertilised plus thinned treatment, after adjustment for initial volume differences, was 73% greater than control. The difference predicted from 1978 tree foliar weight estimates and foliar efficiency was 63%: 38% associated with increased tree foliar weight and 25% with increased foliar efficiency. This last result is examined in the light of other findings.

1.00 INTRODUCTION

Fertilisation and thinning treatments generally result in a significant positive stem volume response in radiata pine[1] (Waring, 1971b; Woollons and Will, 1975). Moreover, the two factors interact in such a way that no large response to fertilisation materialises in the absence of thinning. Some investigators suggest that a change in stem form may be associated with fertilisation (Mead, 1974; Whyte and Mead, 1976), or with the combination of treatments (Waring, 1971b; Woollons and Will, 1975).

The biological mechanism(s) underlying a fertilisation x thinning interaction have not been adequately described. Explanatory hypotheses may include changing micro-climatic conditions, changes in soil flora and fauna; treatment influence upon nutrient cycling patterns; increased assimilation rates or increased photosynthetic potential; improved plant water efficiency; and changes in the production, accumulation, and distribution of foliar biomass in the green crown. This list is, however, far from complete, as the combined effects of fertilisation and thinning are known to be complex.

1.10 NATURE AND SCOPE OF INVESTIGATION

This study is concerned with aspects of stand and individual tree biomass response following a combination of fertilisation and thinning treatments, with particular emphasis accorded to foliar

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1. A list of common names and the corresponding Latin binomials is found in Appendix 1.

biomass relations in the green crown of radiata pine. The green crown is seen as a highly responsive intermediary between silvicultural treatment and stem response, as well as a valuable tool in interpreting changes in the latter (Duff and Nolan, 1953, 1957; Labyak and Schumacher, 1954; Reukema, 1961; Larsen, 1963; Shinozaka et al., 1964a, b; Hall, 1965; Stiell, 1969; Shea and Armson, 1972; Beckwith and Shackelford, 1976).

Estimates of biomass production have historically been derived from single point-in-time harvests (Art and Marks, 1971). In forestry studies individual trees or relatively small areas are usually defined as the sampling unit. Harvesting techniques are limited in certain applications because they involve, by definition, destructive sampling, and thus permit no further observations of the sample unit. If the absolute change to be estimated is small, i.e. harvests close together in time or growth rates slow, the accuracy of the estimate of change is adversely affected by the decreasing ratio of change to between-sample variation. Harvesting is used in this study to provide annual estimates of stand and individual tree biomass production, but in order to examine short-term, within-crown dynamics another sampling methodology is explored.

This study describes a non-destructive sampling method which permits repeated estimation of biomass components within zones of the live crown of individual radiata pine trees. The need for detailed within-crown studies has been noted by several authors and most recently by Ek (1979) who also pointed out some of the advantages of a non-destructive estimation method.

The procedure described here is analogous to the double-sampling technique commonly used to estimate stand biomass. This involves taking relatively large numbers of non-destructive stem dimensional measurements as well as measuring an independent sample of stand trees to obtain the relationship between stem dimension(s) and the variable of interest; i.e. total above-ground tree weight. Stand above-ground total weight may then be calculated by a number of summation techniques.

In applying this technique to give repeated estimates of total tree above-ground biomass, the dimensions of all individual branches of a given tree are measured (comparable to the measurement of stems within a stand). An independently derived relationship of the branch variable of interest, i.e. total branch weight, is obtained by regression upon branch dimension. Total tree branch weight may be obtained by the summation of individual branch weights;

$\sum_{j=1}^{n} b_j$, where b_j represents the predicted weight of the jth branch and n the number of branches in the tree.

If the green crown is stratified prior to measurement of the branch dimensions, and if the weight-dimensional relationships are determined by stratum, the estimate of total crown weight is given by

$\sum_{i=1}^{n} \sum_{j=1}^{m_i} b_{ij}$, where m_i is the number of branches in the ith stratum, n is the number of strata per tree, and b_{ij} the predicted weight of the jth branch in the ith stratum.

To provide estimates of stem biomass on these same trees, stem sectional measurements were taken from which over-bark stem volumes were derived. The relationship between over-bark volume and oven-dried stem plus bark weight was calculated annually from an independent sample and used to predict the bole weights of sample trees. The sum of bole weight and total crown weight is given as an estimate of total tree above-ground biomass. This is a theoretical underestimate, as the method ignores stem needle and stem cone weight. It is difficult to assign accurate confidence limits to a total weight estimate derived from many predicted component weights, but the approach does have the advantage of providing estimates of treatment response in terms of individual biomass components.

In order to relate crown foliar biomass response to stem profile development, a series of over-bark stem diameter measurements were taken at fixed points on the sample trees for which crown biomass had been estimated. Analysis of stem profile development over the two year period following trial initiation, and the concurrent estimates of biomass production of the same trees, provides the basis for interpreting the fertilisation x thinning effect in radiata pine.

All data in this study were derived from a common experimental source; however, for the purposes of explanation it is convenient to identify four primary data pools. A brief introduction to the nature of the data is given here in order to outline the development of the investigative methodology and the role played by the different data sources in attaining the study objectives. A fuller description of the sampling techniques and measurements is given in the section numbers referenced.

Data Source 1: Stand sample tree measurements (Section 4.31)

A sample of 4 trees per plot were randomly selected in August 1977 and subject to partial replacement at 3-month intervals until August 1978. Monthly measurements were made of this sample. A "permanent" sample of 12 trees per treatment was selected in October 1977 and these trees were re-measured in October 1978 and 1979.

On measurement occasions stem diameters at fixed points and the diameters of all live branches were recorded.

Data Source 2: Stand measurements (Section 4.32)

Tree diameters at breast-height, over-bark (d), and total heights were measured at annual intervals in June 1977, 1978, and 1979. All inner plot trees were measured in 1977, but on the re-measurements total tree height was determined for only a sample of 10 trees in each plot.

Data Source 3: Full-tree biomass (Section 4.33)

Whole trees (above-ground) were collected annually in August 1977 (pre-treatment), August 1978, and August 1979 and were broken down into biomass components. The relationships of the biomass components to tree stem dimensions were calculated. Data from the green crown of sample trees provided regressions of branch variables upon branch diameter by crown position and treatment.

Data Source 4: Branch biomass (Section 4.34)

These data were collected to provide regressions of branch variables upon branch diameter by crown position and treatment.

The regressions were determined periodically between the annual full-tree biomass occasions. Sampling occurred at three-monthly intervals in December 1977, March 1978, and June 1978. When branch regressions from Data Source 3 (DS3) and Data Source 4 (DS4) are combined they span a time period of two years following treatment. A further branch biomass was carried out in February 1978 in support of another research project.

Figure 1 traces the development of the methodology in this study. There is much information included within the body of the thesis which is not presented in the flowchart. It does, however, represent the salient features of the research from which all secondary investigations arose. Of major importance in Figure 1 is the Annual Estimate of Stand Biomass Production derived from DS2 measured stem dimensions and the DS3 relationships of whole-tree biomass components to stem dimensions. The Annual Estimate of Individual-Tree Crown Biomass is calculated in a similar manner using inputs from DS1, DS3, and DS4.

In this way, the within-crown response to treatment, considered as biomass production, accumulation, and distribution, is assessed and compared directly to the stem profile development of the same trees over the same period of time.

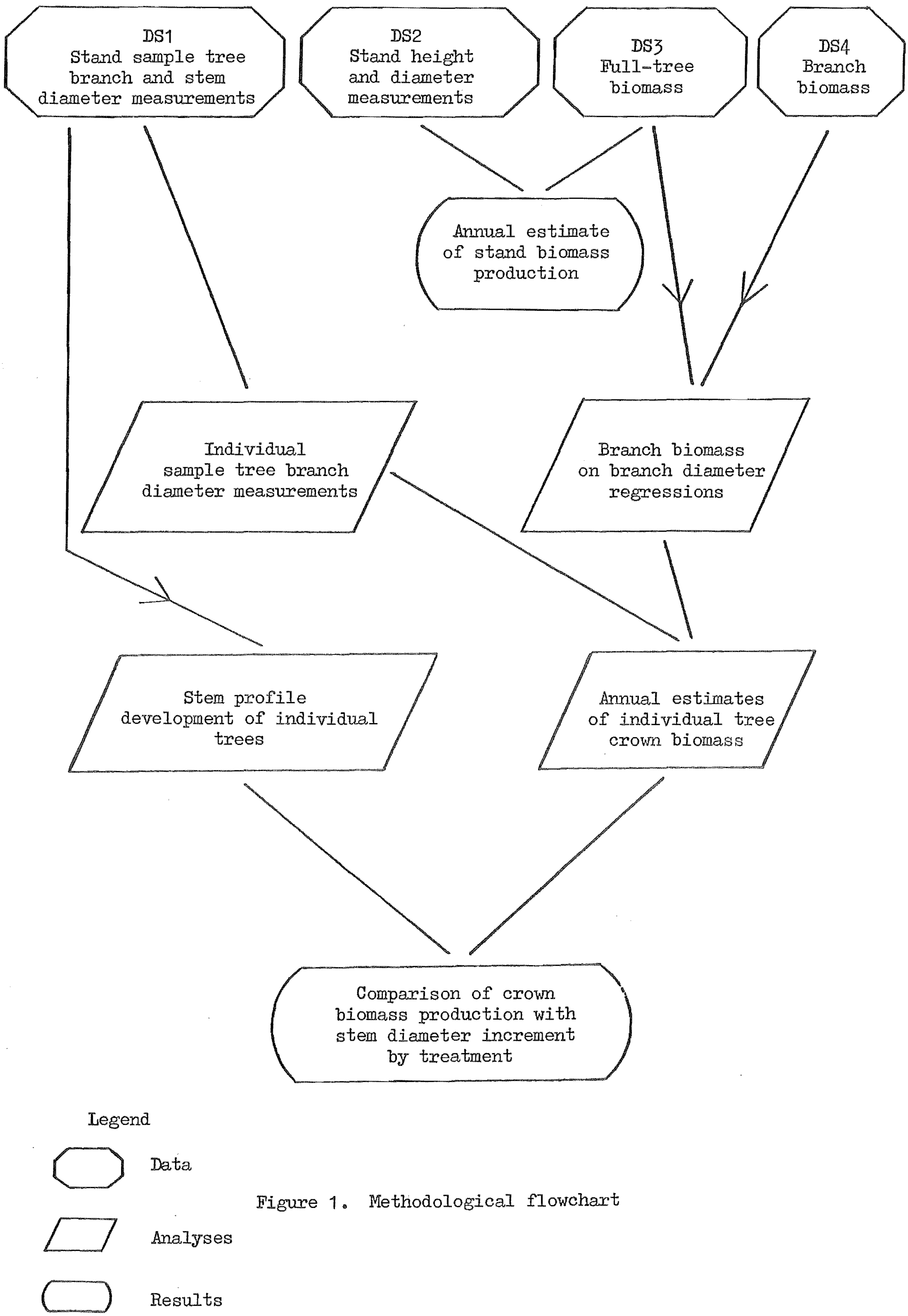


Figure 1. Methodological flowchart

2.00 LITERATURE REVIEW

As background to this study, literature from three distinct areas in forest research is considered. Firstly, published works on fertilisation and thinning are reviewed separately and collectively. Secondly, the theory and measurement of stand and individual tree biomass production is reviewed, with particular reference to radiata pine. Finally, the growth habit and terminology relevant to radiata pine in New Zealand are described in order to clarify sampling procedures presented later, as well as define the biomass components considered in the study.

2.10 FERTILISATION

Primary emphasis in this review is given to the nitrogenous fertilisation of established stands, as to try to cover the widespread use of fertilisers in forestry is beyond the scope and need of this study. Mead and Gadgil (1978) have reviewed New Zealand experience in stand fertilisation and report that applications of approximately 200 kg ha^{-1} of N at mid-rotation on Central North Island radiata stands may realise volume responses exceeding 8 m^3 ha^{-1} an^{-1}. Nitrogen applied at the same rate on mid-rotation stands in the Canterbury Plains of South Island may realise approximately 5 m^3 ha^{-1} an^{-1} because of generally lower site productivity and summer droughting (D.J. Mead, pers. comm., November 1979). Mead and Gadgil (1978) further note that responses on infertile sites are short-lived and that the best results are obtained in combination with thinning. The inter-relationship of N and P has led to the practice of applying both elements if foliar or soil analysis indicates that P is marginal.

The distribution of stem diameter increment in response to fertilisation has been reported to differ from that of controls by Waring (1971b), Kawana and Leaf (1973), Mead (1974), and J.E. Barker (pers. comm., 1977). Alternatively, Gessel et al. (1969) found no fertilisation effect in the distribution of diameter increments of Douglas fir, although the increment patterns were described as irregular and mention was made of the possibility of greater stem diameter growth in the upper crown of fertilised trees. Miller and Cooper (1973) reported on a 36-year-old stand of Corsican pine and found no significant differences in stem diameter increment distribution following fertilisation. These authors suggested that fertiliser response could be adequately described as growth on an accelerated time scale. The lack of consistent mensurational techniques in fertiliser trials has given rise, at least in part, to these variable results. Shephard (1978) could find no significant difference in patterns of diameter increment along the bole of red spruce. After 5-7 years response to N and N + P fertilisation was distributed uniformly along the stem.

Nitrogen fertilisation is widely reported to increase foliar mass or leaf area (Will, 1965; Brix and Ebell, 1969; Wells, 1970; Will, 1971; Weetman, 1971; Keller, 1973; Baker et al., 1974; Calvert and Armson, 1975; Will and Hodgkiss, 1977; Albrektson et al., 1977). This response may be associated with increased leaf size (Watson, 1952; Calvert and Armson, 1975; Will and Hodgkiss, 1977), increased leaf numbers (Watson, 1952; Helms, 1964), or increased foliar retention (Madgwick, 1975; Madgwick et al., 1970). However, Will and Hodgkiss (1977) have reported a decreased needle retention with improved nutrient status, attributing this to increased light competition.

The response in stem volume increment of fertilised trees may be interpreted as an increase in net assimilation rates (NAR), independent of possible changes in foliar biomass, leaf area, or needle retention. Published reports for different species and nutritional levels are conflicting. Watson (1952) examined the NAR of several agricultural crops with respect to nutrient status, season, and climate, and confirmed the results for different leaf areas. He concluded that while the NAR may vary, a significant increase in yield was more likely to be associated with an increase in leaf area. NAR was constant over all but very limiting levels of N nutrition and was found to decrease with declining water availability. Brix and Ebell (1969), Tamm (1975) and Albrektson et al. (1977) concluded similarly that while fertilisation may increase photosynthetic efficiency, the effect is less than that of increased foliar mass.

Kramer and Kozlowski (1960) and Keller (1973) reported increased photosynthetic rates with improved N status while Helms (1964) found no increase of NAR in Douglas fir in the year following fertilisation. Brix (1971) reported a temporary increase in photosynthesis over relatively high light intensities but also measured an increase in dark respiration. The same paper quotes Pirson (1958), and Keller and Koch (1962) (not seen), as having increased photosynthetic rates by fertilisation. Keay et al. (1970)

found increased rates of C^{14} fixation in all age classes of fertilised material over control. Recent work on thinned, and thinned and fertilised 9-year-old radiata pine suggested that differences in photosynthetic rates per unit foliar area were small and appeared non-significant in the limited sampling possible with thermo-electrically cooled cuvettes (Benecke, pers. comm., November 1979).

Glatzel (1973), working with Norway spruce pot plants, demonstrated increased water-use efficiency with increasing levels of N nutrition. Differences were most pronounced early in the growing season and on hot, clear days. The effect was attributed to improved stomatal control. In the field, Brix (1972) could find no difference in fertilised and control Douglas fir under drought conditions.

Woollons and Will (1975), Donald (1976), and Mead and Gadgil (1978) report no height response to fertilisation of radiata pine. Calvert and Armson (1975) measured an increase in leaf size following fertilisation of jack pine, but no evidence of increased height growth. Lateral branch extension growth of radiata pine after N fertilisation is reported by Will (1965), and Will and Hodgkiss (1977). Smith et al. (1970) reported similar results with loblolly pine. In studying N and P deficiencies of radiata Will and Hodgkiss (1977) reported effects to be most pronounced upon branch, then stem, then apical or height growth. The ratio of stem wood to total crown weight decreased with increasing nutrition; this trend was reported by Cromer and Hansen (1972) for loblolly pine. However, Manley (1975) found the ratio constant in radiata pine.

Will and Hodgkiss (1977) found significant clonal effects in response to nutrient levels. Similarly, Roberds et al. (1976) examined 35 families of loblolly pine and found between family differences at low levels of nutrition to be small but at high levels to be large.

Fertiliser responses of stands and individual trees are thus seen to vary by species and site; however, a few generalisations can be made. Nitrogenous fertiliser, in other than remedial situations, has little influence on height development. Stem volume, and to a lesser degree, basal area responses, may be large. A change in stem form may result from fertilisation of radiata pine. It is suggested that foliar efficiency may be influenced by fertilisation, although the biological mechanism(s) influencing this appear interrelated in a complex manner. Increased foliar area or foliar biomass contributes relatively more to increased productivity following fertilisation than does changing photosynthetic capacity.

2.20 THINNING

The review and discussion of thinning is confined to consideration of effects upon crown growth and development, and upon the distribution of stem diameter increment. No attempt is made to review the criteria which may influence selective thinning or the many possible orderings of such criteria which occur in the pursuit of management goals. The thinning operation carried out in this study conforms to the S.A.F. (1971) definition of thinning; that is, a felling in an immature stand to accelerate diameter increment and improve average tree form without permanently breaking the canopy.

Qualitative descriptions of crown shape and size are many but quantitative descriptions too few (Tadaki, 1966; Honer, 1971a; and Ozlanyi, 1977). Quantitative, within-tree productivity studies have been called for by Shepherd (1976) to aid in interpreting effects of thinning. The published material to date emphasises the more easily measured gross crown variables such as tree height, crown length, crown length ratio, and crown volume.

Height response to thinning is reported to be slight or non-significant by Dell and Collicott (1968), Keister et al. (1968), Bassett (1969), van Laar (1969), Shepherd and Forrest (1973), and Siemon et al. (1976). Live crown length and crown length ratio are constant following canopy closure (Beekhuis, 1965; and Stiell, 1966), although the latter has noted that after canopy closure crown elongation is consistent at the growing tip but mortality is inconsistent in the lower crown. Stiell (1966) further points out that only in developing stands will the relationship between stem diameter below green crown and crown size be stable. Kramer (1966) has suggested that under constant stand density, derived from repeated light thinnings, crown length ratio must decrease with time as crown length remains constant. Beekhuis (1965) found that crown length of radiata pine following thinning was influenced by stand density and predominant mean height. Keister et al. (1968) examined slash pine stands at age 40, following thinning to 4 densities at at age 13, and could find differences in crown length and crown length ratio between control and thinned plots, although no difference was apparent between thinned levels other than control. The crowns of control trees were significantly shorter than those having undergone thinning.

Crown width was shown to decrease with increasing density in radiata pine (van Laar, 1963), while height to green crown increased. Crown diameter was shown to increase in response to thinning but was less affected than crown length (van Laar, 1973).

Crown expansion following thinning may be interpreted as a specie's ability to utilise available growing space. If height response to thinning is negligible, crown expansion must rely upon the response of branch shoot apices. The timing of response may be influenced by bud physiology (Lanner, 1975). Kozlowski (1971) states that as a general rule, gymnosperms with fully preformed shoots decrease more or less regularly in branch growth from the apex downward. Smithers (1954) found that rates of branch growth in red pine decreased with branch age and were lowest in trees aged 45 years for all branch ages. It was concluded that little crown response in red pine past age 45 could be expected and that crown expansion in younger trees would be greatest in the upper crown. Riding (1978) reported that branch potential was correlated with the size of shoot apices and that this in turn was related to exposure. On the unshaded side of red pine no significant size difference in shoot apices was observed over tree height. Shaded branches, however, differed significantly above and below the point of maximum shading determined by crown closure. Branch apices in the lower shaded crown were smaller than those found above. Reukema (1964) measured a temporary reduction in crown expansion in the upper crown of Douglas fir and could find no difference in response of released and unreleased sides of the crown.

Thinning is reported to increase photosynthetic area (Kramer and Kozlowski, 1960), apparent photosynthetic capacity (Helms, 1964), foliar weight (Weetman, 1971; van Laar, 1973), and wood production per unit foliar weight (Stiell, 1966; van Laar, 1973), although Sieman (1973) found no increase in foliar efficiency with thinning. Response to thinning has been attributed to the increased availability of growing space, increased light availability to intermediate branches, and reduced competition for soil moisture and nutrients (Forward and Nolan, 1961a, b). van Laar (1973) associated thinning response in radiata pine with improved moisture relations. Butcher and Havel (1976) have demonstrated that girth increment follows the drying and wetting cycle of the soil rather than precipitation, and Haberland and Wilde (1961) and de Vries and Wilde (1962) have given examples of the influence of thinning on stand soil water availability.

Evaluation of stem form and stem taper change in response to thinning must take into account that both form and taper are related to tree diameter (Sjolte-Jorgensen, 1967; Cromer and Pawsey, 1957). It is necessary to separate the general effect of increasing tree diameter, as a function of increased spacing, from a true form or taper change. van Laar (1969) similarly cautioned that the analysis of diameter growth at varying stand densities must first eliminate the influence of stem diameter and crown length.

Larson (1963) noted that measured bole response to treatment often ignored the importance of crown characteristics in its determination, and that thinning by influencing crown characteristics must affect tree form. Work by Stiell (1964), Bassett (1969), and

Berry (1974) has been unable to support this, although Siemon (1973) did support Larson's contention with experiments on thinned radiata pine. In this 23-year-old stand, stem form changes in response to thinning were consistent over all measured diameter classes. Stem form was found to change most in unthinned or lightly thinned stands, while stem taper changes were most apparent in heavily thinned stands. Sjolte-Jorgensen (1967), in a review of spacing influences on coniferous plantations, noted that form factor generally declined with increased spacing but that differences in taper were so small as to be unimportant in consideration of yield. Published results from Northern Europe indicate that stem taper is associated with degree of branchiness (Hakkila, 1969), which in turn is related to the history of density in stand development. The same author quotes three Finnish papers (not seen) in support of this contention, referring to Scots pine and Norway spruce.

Thinning, as reviewed here, is seen as a silvicultural treatment giving rise to many complex responses. Gross crown size generally increases with thinning although site factors may influence responses markedly. Height response is variable with much of the noted crown expansion being associated with growth of branch apices. Live crown lengths and crown length ratios are affected by thinning. The response of stem form to thinning appears to be specific to site and species and has not often been critically evaluated free of the influence of tree size.

2.30 FERTILISATION AND THINNING

Published results of combined fertiliser and thinning treatments are variable and difficult to assess due to different treatment rates, site factors, and species. The response variable of primary concern has been volume, although results on foliar biomass and net assimilation rates have also been published. The wide-ranging results may be attributed in part to the sensitive timing required by the silvicultural operations (Woollons and Will, 1975), and to the different mensurational techniques employed in the attempt to quantify response to treatment. Breast height diameters and two dimensional volume tables have been widely used to indirectly estimate volume responses, although considerable evidence exists that volume response may be associated with a re-distribution of diameter increment along the stem, necessitating direct stem measurements (Waring, 1971a; Woollons and Will, 1975). Whyte and Mead (1976) recently considered mensurational techniques for detecting fertiliser response and demonstrated that basal area was a poor predictor of actual response. Sectional measurements or stem analysis on individual plots or on a single-tree basis were advocated, as much of the volume response to fertilisation occurred in the upper log.

A number of fertilisation and thinning trials have been reported in Douglas fir in the Pacific Northwest of North America. No significant re-distribution of stem diameter increment in fertilised trees with or without thinning was found (Gessel et al. 1969). Bower (1973) detected no stem form change in Douglas fir following thinning and fertilisation. Steinbrenner (1968) reported that Weyerhauser's emphasis had shifted from fertilisation for early cone production to fertilisation in combination with thinning for greatest volume response. Miller and Williamson (1974), in a 2^2 factorial in fertilisation and thinning, reported different responses with Douglas fir on a sandy loam soil than on a clay site. Basal area growth was consistently less on the sandy loam; fertiliser resulted in only a small non-significant gain over control, but the combined treatment showed a large significant gain for the first 3 years. On the clay soil, although absolute growth rates were high, significant response to treatment was limited to the main effects. Fertilisation was significant over a 4 year period but decreased in significance annually. The authors suggest that thinning may have the greatest long-term effect.

De Bell et al. (1975) found a weak diameter response in old stand western hemlock when thinned before fertilisation but no response to fertilisation without thinning.

In black spruce trials in Canada, Weetman (1968, 1971) found significant responses to the individual treatments but no interaction in basal area increment. In a later trial some evidence of a volume interaction was noted (despite the fact that volumes were calculated from local volume tables) but the effect was not significant (Weetman, 1974).

Malac (1968) found the individual response of slash pine to N fertilisation to be largely independent of densities between 300-900 stems acre^{-1} (741-2224 stems ha^{-1}).

Waring (1971b) noted an 11% increase in basal area response to thinning following re-fertilisation of a 22-year-old plantation of radiata pine. Stem increment in the third year after treatment, measured at 25 feet (7.62 m), showed a 23% increase in over-bark sectional area. Woollons and Will (1975) used a Barr and Stroud dendrometer to measure over-bark upper stem diameters and concluded that volume response occurred partially as a result of change in stem form. The same paper emphasises the need to thin stands not more than 3 years prior to fertilisation. Response to fertilisation and thinning was sustained for up to 7 years. Kawana and Leaf (1973) also recommended fertilisation in the 3 year period following thinning of sugi.

In explanation of thinning x fertiliser interactions Tadaki (1966) has pointed out that as leaf biomass tends to stabilise in closed stand conditions, the input of an artificial site improvement (i.e. water or fertiliser) would be expected to have a lesser effect in closed stand conditions than in open, due to the reduced capacity of leaf biomass to respond. Waring (1971b) has postulated a similar idea suggesting that fertilisation x thinning interactions can be explained by his theory of free growth (Waring, 1969).

Despite the number of trials investigating combined fertilisation and thinning treatments, there are few critical analyses of stem volume interactions. The primary reason for this has been unsuitable mensurational techniques which fail to recognise the importance of upper stem diameters. Thus, basal area has often been uncritically used as the response variable. In radiata pine there is reason to believe the volume interaction occurs, at least partially, as a result of a significant change in stem form.

2.40 BIOMASS ESTIMATION

An increasing interest in quantifying biomass production of individual plants, stands, and ecosystems is evident over the past two decades. Forest research into biomass production has originated from diverse fields including: fire management, whole-tree harvesting, agro-forestry, ecosystem modelling, and energy production from forests. This list is by no means complete, but serves to indicate the wide scope of reported biomass investigation.

Techniques for estimating biomass production have undergone considerable revision over time. Several reviews of methodology and underlying theory are available (Ovington and Madgwick, 1959; Baskerville, 1965a; Satoo and Senda, 1966; Ovington et al., 1967; Attiwell and Ovington, 1968; Madgwick, 1970, 1971; Baskerville, 1972; and Zavitkovski et al., 1974).

Generally, regression techniques are advocated for stand estimation in preference to mean tree approaches. Attiwell and Ovington (1968) advocated the sampling of a number of trees distributed over the diameter range, because proportions of leaf, branch, trunk, and root biomass vary with tree size. Madgwick (1970) noted that trees of mean stem dimensions, usually interpreted as mean diameter, basal area, or even mean height, tended not to be trees of average biomass components. Several papers critical of the mean tree approach are cited.

The choice of the appropriate form of the regression model has also received considerable attention. Crow (1971) considered linear, exponential, allometric, hyperbolic, and multiple regression models in fitting jack pine biomass data. The allometric form, with breast height stem diameter as the independent variable, was given as the best general form, although no single model provided the best fit for all tree component weights. Ohman et al. (1976) considered linear, allometric, exponential, and hyperbolic regression models, and selected the allometric for estimation of shrub biomass in Minnesota, although the linear model provided the lowest residual mean squares.

In choosing the independent variable for regression Crow (1971), Honer (1971b), and Madgwick (1971) noted the advantage of d^2h over d when site, age, or stocking was variable. Madgwick (1971) found little difference in the accuracy or precision of bole weight estimates derived from regression upon log d or d^2h. For canopy components, diameter (d_c) below live crown was considered. The bias in randomly sampled estimates of live branch weight using d, d^2h, and d_c were 6, 6 and 2% respectively. Variability was reported to be high in all estimates. Predicted tree foliar weight resulted in a bias of 6, 6 and 10% for d, d^2h, and d_c respectively, with variability little affected by the choice. In his summary, Madgwick (1971) suggested that the disadvantages in terms of cost and time in measuring tree height and diameter at crown base were probably not justifiable within a single stand.

Honer (1971b) predicted component tree weights of open and forest grown balsam fir using $\ln w = b_o + b_1 \ln d + b_2 \ln h$. His tests for significance of b_2 in open grown trees gave positive results for only 1 out of 8 biomass components tested. In forest grown trees, height proved to be a significant addition to the predictive equation for 5 out of 8 components.

Individual tree biomass has been successfully related to sapwood area (usually at breast height) by several authors (Grier and Waring, 1974; Whitehead, 1978; Snell and Brown, 1978; and Rogers and Hinckley, 1979). Sapwood area is a biologically appealing variable but as pointed out by Grier and Waring (1974), the species studied must be taken into consideration. Radiata pine forms heartwood at 13 to 18 years of age in Australia (Nicholls and Dadswell, 1965), therefore basal area and sapwood area may be synonomous until that age. Whitehead (1978) found foliage area to be linearly related to sapwood cross-sectional area at 1.30 m and independent of spacing for Scots pine. Grier and Waring (1974) found sapwood area as the independent variable to be an improvement over diameter for large trees. Snell and Brown (1978) compared sapwood cross-sectional area with total cross-sectional area and found increased precision with the former in 3 out of 7 species tested.

Rogers and Hinckley (1979) further considered sapwood area by identifying those sapwood rings in oak which actively transport water. This current sapwood area (CSA) was compared with sapwood cross-sectional area and total cross-sectional area, and was found to be the best predictor of tree foliar weight and tree foliar surface area.

Aggregating individual tree biomass estimates to derive stand estimates has been reviewed by Madgwick (1976), who examined and discussed three main methods.

(1) Stand Weight = sum of weights estimated from regression.

$$(2) \quad \text{Stand Weight} = \frac{(\text{stand basal area}) \cdot (\text{total weight of sample trees})}{(\text{total basal area of sample trees})}$$

$$(3) \quad \text{Stand Weight} = (\text{number of trees in stand}) \cdot (\text{average sample tree weight})$$

The difficulty in comparing methods to determine precision was emphasised, as was the need for measured values of total stand weight to allow reliable estimates of bias associated with a given methodology.

Madgwick and Satoo (1976) carried out simulated sampling to derive estimates of the stand biomass of 9 stands of known weight. Logarithmic regression estimates, after correction for inherent bias due to the transformation, then summed for all trees, were found to over-estimate known stand component weights by approximately 3%. Regressions based on d^2h as the independent variable gave mean estimates closer to the true means than regressions on d alone. It was noted, however, that the 9 stands considered varied widely in tree size, species, and stand type. Stratified sampling gave rise to over-estimates of stand weights. The variance of stand estimates was discussed and two methods compared (Madgwick and Satoo, 1976). In general, the variation of estimates resulted in a small average bias of minor importance compared with the variation between replicated samples (Madgwick and Satoo, 1976).

Stand weights are seldom given with error estimates although techniques have been published by Finney (1941) and Mountford and Bunce (1973) by which confidence limits for stand estimates may be derived. Madgwick and Satoo (1976) commented on stand weight confidence limits and suggested that the measured stand values were contained within the confidence limits less often than expected by theory, because: (1) random and stratified sampling gave smaller residual mean squares about the regression line than expected for all trees; (2) the bias of estimated means caused the confidence interval to be displaced; and (3) that estimates of stand weights from stratified sampling are skewed by large over-estimates.

The inherent bias in "re-transformed" arithmetic values from logarithmic regression was pointed out by Meyer (1938). This bias results because if the distribution of ln(y) on a given ln (x) is normal, then the distribution of y about x must be skewed (Baskerville, 1972). "Correction factors" have been published to adjust the bias associated with the mean and variance of the transformed values (Meyer, 1938; Finney, 1941), and their applicability discussed by Madgwick and Satoo (1976). The magnitude of the uncorrected bias has been estimated at 10-20% of the total biomass for a given component (Baskerville, 1972) and 1-16% of stand biomass (Madgwick and Satoo, 1976). It is always an underestimate of actual weight. The latter authors advocated use of the correction term published by Finney (1941) rather than the abbreviated form of Meyer (1938), although they noted that with 5 sample trees the residual mean squares were so small as to approximate the same results.

Published biomass figures for individual trees and stands are numerous and beyond the scope of this study to consider. (A summary of world biomass data has been given by Art and Marks (1971).) Pertinent to this study are the dry matter production figures, given in Table 1. The Australian data are drawn from Forrest and Ovington (1970); the New Zealand data from Madgwick et al. (1977). In considering the available literature, these studies provide the best basis for comparison to figures given in this thesis.

Table 1: Oven-dried weights of above-ground material in age series of <u>Pinus radiata</u>. Weights given in tonnes ha^{-1}.

	Stand Age*				
	3	5	7	9	12
Stem ha^{-1}	1483	1492	1458	1470	1560
Basal area ($m^2 ha^{-1}$)	-	2.0	16.0	25.0	32.9
Average height (m)	1.4	3.1	7.9	12.1	15.6
Branches minus leaves	0.2	1.2	14.9	9.9	18.7
Branch leaves	0.4	1.9	11.2	8.4	9.2
Bole bark	0.1	0.3	2.7	5.6	8.8
Bole wood	0.3	2.1	21.1	48.2	80.7
Female cones	0	0	0.4	0.5	0.7
Total by summing total tree weights	1.2	5.6	50.7	73.4	118.8

* adapted from Forrest and Ovington (1970) Table 1, p.178 and Table 2, p.180. Tamut site.

	Stand Age*				
	2	4	8	9	10
Stem ha^{-1}	2496	2347	1507	544	544
Basal area ($m^2 ha^{-1}$)	0.0	7.4	29.4	12.3	20.8
Height (m)	1.05	3.91	10.98	17.00	16.71
Live branches	0.12	6.56	23.79	5.53	11.38
Leaves (all ages)	0.36	7.15	5.92	3.40	5.85
Stem bark	0.06	1.27	5.26	3.60	4.78
Stem wood	0.17	7.19	45.99	29.07	49.59
Cones	0.00	0.00	0.09	0.60	0.21
Total (summing all components in original table)	0.71	22.17	82.63	42.20	71.86

* adapted from Madgwick et al. (1977) Table 1, p.449. Kaingaroa site.

While there is a considerable amount of published information on tree and stand biomass production, there are fewer data available describing the distribution of component weights within the crown, the change in biomass distribution over time and in response to treatment, and the relative productive capability of areas within the crown. Yet these relationships are basic in characterising the crown and its subsequent influence upon bole wood production. Complex gradients of light availability, physiological age of tissue, distribution of hormones, microclimate, and mechanical stress are present in the crown, in both horizontal and vertical planes. These have led to the simplistic approach of considering the crown as an essentially homogeneous unit variously described by leaf area, foliar weight, crown volume, and surface area. The degree to which these simplifications may obscure results is not easily established, as comprehensive crown studies are few and restricted to small numbers of trees.

Whittaker (1965) noted the influence of branch age and vigour on the allometric relationship between branch diameter and branch weight. The same author found that the large error variance associated with a single fitted line for branches of all ages and apparent vigour was reduced, when samples were selected representing specific sizes, age classes, and crown positions.

Riedacker (1971) considered the prediction of branch biomass components and noted that a variable accounting for position in crown improved foliar weight prediction. It was noted that further study on the relationship of branch position and needle weight was required.

A detailed study by Madgwick and Jackson (1974) reviewed previous publications relating branch and crown weight to branch variables, and confirmed that clonal differences exist in branch relationships. A strong association between branch age and 1-year-old needle weights was found, which included a significant interaction between branch size and age. An independent data set was analysed by the inclusion of relative height (RH) as an independent variable. The term (RH) and $(RH)^2$, when included with branch size, was found to be a statistically significant prediction variable. The interaction between branch size and relative height was not significant nor was date of sampling, which covered a period of one year. An indication of the accuracy of predicted weights from branch variables is given by Madgwick and Jackson (1974). Estimates based on diameter of branch alone and corrected for logarithmic bias ranged from 79 to 119% of actual 1-year-old needle weights. Total needle weights were predicted within 70 to 102% of measured weights.

Estimates of 1-year-old needle weights were presented by crown position and indicated a consistent underestimate. When the term (RH) and $(RH)^2$ was included as well as branch diameter, the underestimates were over-corrected to give a positive bias. The authors noted that two principle sources of bias in estimates of canopy weight components existed. These were: (1) the aforementioned logarithmic bias, and (2) an undetermined biological gradient throughout the crown, which was hypothesised as a shading effect. Thus, in order to increase the predictive accuracy of branch regression estimates, unknown factor(s) must be recognised and accounted for in the regression model(s) chosen.

Ek (1979) found substantial improvements in the predictive abilities of models incorporating branch diameter, height of branch, and the ratio of total tree height to stem diameter as a stand density measure, over models using branch diameter alone. He further reported that branch height was helpful only in combination with stand density for predicting branch wood + bark weights, although alone it was highly significant in predicting branch foliar weights, and found to be independent of spacing. Ek also considered the possibility of field sampling relatively few branches to determine the coefficients in models to predict canopy weights. He pointed out the usefulness of such a non-destructive sampling methodology for repeated measurements.

Swank and Schreuder (1974) advocated crown stratification prior to sampling white pine for surface area and biomass estimation. Ozlanyi (1977) divided the crown of an oak-hornbeam ecosystem into 1 m vertical strata for sampling and predictive purposes.

Kay (1978) determined that the relationship between branch foliar weight and branch diameter varied by position in crown and that the largest residual mean squares from regression were found in the upper and lower 20% of the crown. Instead of incorporating a height or relative height term this author calculated separate branch regressions at crown sections defined arbitrarily by dividing the live crown into 10 equal strata.

The independent variable used in branch regressions is commonly over-bark diameter, measured a specific distance from point of insertion into the stem. Loomis et al. (1966) and Madgwick and Jackson (1974) considered incorporating branch length, but argued that the gain in precision was not justified by the extra costs incurred.

Tree biomass studies indicate that the vertical distribution of foliage throughout the crown follows a normal or near-normal distribution pattern (Tadaki, 1966; Stephens, 1969; Gary, 1976; Ozlanyi, 1977; and Gary, 1978). However, the influence of silvicultural treatment upon crown structure and development is not well documented. Siemon (1973) and Siemon et al. (1976) described within-crown response of individual trees to the thinning of a 23-year-old stand of radiata pine in Australia. Increased foliar weight was reported in the crowns of heavily thinned, as compared with lightly thinned, trees. The increased foliar weight was found in the upper crown along with increased branch diameter growth. The frequency of branches in the ≤ 1 cm diameter class was reduced, while the frequency of branch diameters between 3 and 5 cm increased with severity of thinning.

van Laar (1976) called for further within-crown investigations with respect to site and silvicultural effects. This author suggested multi-stage sampling techniques on randomly selected trees and branches, or independently calculated regression coefficients and an enumeration of all branch diameters of sample trees. Sampling strategies reflect the difficulties arising from great within and between tree variability.

Techniques for individual tree and stand biomass estimates are well-developed and supported by a large body of literature. However, the comparison of studies is made difficult by a lack of uniformity in: (1) the regression models used, (2) the definition of biomass components, (3) the use of fresh or oven-dried weights, (4) the different tree summation techniques to provide stand estimates, and perhaps most importantly, (5) the almost complete absence of published error estimates.

Much less information is available on within-tree biomass response to silvicultural treatment. Further work in this area is required if biomass investigations are to be used not only as a measure of productivity, but also as an interpretive tool.

2.50 GROWTH OF RADIATA PINE IN NEW ZEALAND

In this biomass study, where total tree weight is considered as the sum of several component weights, it is necessary to define and adhere strictly to a standard terminology. As the biomass components in this study are defined in relation to the growth habit of radiata pine, a brief review of the physiology of stem and crown growth and development is warranted. Wherever possible, published discussion on terminology is considered, and if consistent with this study, accepted, but the primary aim in definition of terms is not to conform necessarily to previous work, or to offer definitions for general usage, but rather to convey the information required to interpret this study more easily.

Bannister (1962), Bollman and Sweet (1976), and Sweet and Bollman (1976) have considered the terminology of shoot development of *Pinus* spp. in general, and its application to radiata pine in New Zealand in particular. The latter two papers present a rationalised terminology for the description of the growth of pines in both temperate and non-temperate climates. This terminology is accepted and followed in this paper. Radiata pine is described as a species which, beyond the seedling stage, has fixed growth habits. It may, in any single year, produce one cycle of growth consisting of: (1) the initiation of primordia for next seasons' extension growth, (2) a period of dormancy, and (3) extension of the primordia initiated in the previous season (Bollman and Sweet, 1976). This pattern is termed monocyclic. Alternatively, it may produce several such cycles in any one single growing season, this being termed polycyclic. In radiata pine the number of cycles in a single growth year ranges from 0 to 6 (Jacobs, 1938; Fielding, 1960) and averages 2.4 (Fielding, 1960), although Bannister (1962) pointed out that 0 cycles occur only in seedlings.

The term annual shoot is retained from Busgen and Munch (1929) as it defines a stem unit of practical value which has been recognised and used by several authors (Jacobs, 1937; Fielding, 1960, 1967; Bannister, 1962; Forrest and Ovington, 1970; Cremer, 1973; and Madgwick et al., 1977). An annual shoot stem unit begins at the last branch cycle of the previous year and extends to the last branch cycle of the current year. The identification of annual shoots in radiata pine has been described by Jacobs (1936) and Bannister (1962). The stem unit defined above contains lateral branch primordia initiated in the same growing season. In practice it is desirable to be able to associated branch clusters with stem units or annual shoots, but the inclusion of branches of the same year of primordial initiation ignores the observed fact that lateral shoot growth and development occur sequentially throughout the growing season. In the case of later cycles this may not occur until the year following initiation. Thus the first full growing season of lateral shoot extension of the last cycle in, say 1977, will be seen to occur in 1978 along with the terminal shoot extension of the 1978 annual shoot. This concomitant development, subject to the same environmental factors, appears empirically to associate the last cycle of the previous year more strongly with its year of development than its year of primoridial initiation. This is, of course, only true of characteristics undetermined in the pre-formed bud.

For this reason the annual shoot definition, as it pertains to branches in a polycyclic tree, has been modified here to include the last branch cycle of the previous year and exclude the last cycle of the current years' growth. The length of the stem unit remains the same as that given by Bannister (1962); the number of clusters per annual shoot is also the same, the modification being confined to the association of a branch cluster with an annual shoot.

Descriptions of the patterns of growth of radiata pine have been reported by Jacobs (1938), Fielding (1960), Bannister (1962), Cremer (1973), and Bollman and Sweet (1976). The number of cycles produced per annual shoot was shown to vary greatly between trees (Fielding, 1960; Bannister, 1962). The latter found a small but significant age effect in 14-year-old trees, while the former reported that age effects influencing cycle numbers were masked in stands less than 8 years of age. Bannister (1960) reported that site affected cycle numbers in New Zealand radiata pine, but Fielding (1960) reported no site differences in Australian data.

In considering growth response to treatment in conifers, it is important to determine the degree to which a growing season's response is predetermined in the bud. In a typically monocyclic species such as red pine the shoot characteristics may be largely predetermined by the number of primordia initiated the previous season (Lanner, 1975). Albrektson et al. (1977) have noted that genetic potential for response plays a role, but suggest that for Scots' pine the numbers of needles and shoots and their growth patterns are predetermined to the extent that a one year time lag is normal in response to treatment.

In a polycyclic species such as radiata pine, "predetermination" effects are lessened because the dormant bud does not contain the primordia for the entire growing season (Cremer, 1973; Bollman and Sweet, 1976). The latter paper demonstrates that normally only one or more complete cycles are present in the bud at any time, and that the number of structures present is lowest at the time of initiation of cycle one, or in the "spring".

With the growth characteristics previously reviewed in mind, a sampling strategy was designed which utilises annual shoots for stratification within the crown. Branch cycles are further identified within each annual shoot. Thus, the sampling rationale reflects biologically defined crown positions, rather than zones based upon absolute height or percentage crown.

3.00 TRIAL DESCRIPTION

3.10 THE SITE

The experimental area is located within Compartment 18 of Eyrewell State Forest, (Lat. 43° 24'S Long. 173° 16'E) approximately 60 km north of Christchurch, New Zealand, (Appendix 2). Eyrewell forest is situated upon flat fluvio-glacial outwashes, kame terrace deposits, and gravel river fans at 158 m a.s.l.

The following soil description is based on the account given in the "Soils of South Island" (DSIR, 1968). Eyrewell soils are classified within the yellow-grey earth group as having formed under a precipitation of approximately 850 mm an^{-1}, with a seasonal moisture deficiency. Much of Eyrewell State Forest is classified as a Lismore stony silt-loam derived from Greywacke gravels and thin loess deposits. Lismore soils are characteristic of the sub-hygrous yellow-grey earths in frequency of summer drought and presence of a well developed fragipan up to nearly 1 m in thickness. This hard pan, found typically at 1 m depth, is attributed with moisture retention. The same source cautions against the use of mechanical drainage because of the possibility of prolonged summer drought.

The climate of Eyrewell Forest is typical of the Canterbury Plains as a whole. Precipitation is evenly spread over 125 days totalling some 850-950 mm an^{-1}. Long periods of low rainfall are common in the summer months in association with hot, dry north-west Föhn winds. Much of the annual precipitation occurs as a result of cold, southerly air systems. Appendix 3 gives 5-year monthly temperature and precipitation data.

Lismore soils on the Canterbury Plains were originally associated with fescue/silver tussock grasslands and matagouri and kanuka scrub (in undisturbed conditions) (DSIR, 1968).

Eyrewell State Forest records show the original cover in Compartment 18 as manuka scrub and tussock. In 1929 the northern half of the compartment was planted with radiata pine and the southern half with Austrian pine. These crops were subsequently wind-damaged and recovered in stages from 1955-1962. The site was wind-rowed in 1969-70 and alternately deep (1.20 m) and shallow (0.45 m) ripped prior to hand-planting in 1970. Radiata pine nursery stock lot CY68-574C from Rangiora nursery was planted on the rips at 2.4 x 2.4 m spacing. Survival surveys indicated a 93% strike in 1971 when the area was blanked with stock lot CY70-619C to the nominal density of 1680 stems ha^{-1}. The stand was hand-released from competing exotic regeneration in 1973.

When inspected in June of 1977 crown closure was just commencing. An apparent gradient in stand productivity was evident, decreasing from north to south, but variability in stand density and tree diameters was deemed acceptable for the purposes of this trial. Undergrowth in the stand was confined to grasses and a few hardwood shrubs. All stems in the trial area were pruned to 1m above ground level prior to trial establishment in June of 1977.

3.20 TRIAL LAYOUT

Twelve contiguous outer plots 41 x 50 m (0.205 ha) in size were established between parallel windrows. Inner measurement plots, 15 x 25 m (0.0375 ha) were located within each of these major plots. The outer plots (exclusive of the inner) contained approximately 270 trees and the inner plots 60 trees. All outer plot trees were numbered consecutively with aluminium tags. Inner plot trees were numbered 1-60 with large metal tags stapled to the stem at 1 m height. Plot corners were marked with treated 5 x 5 cm wooden posts painted orange for outer plots and white for inner.

Two buffer zones of 30 m width separate the end plots from the adjacent roads (Appendix 4). An access road was cut on the east side of the trial, parallel to the windrow.

Weather screens and rainfall collectors were established in each plot of the central block to augment meteorological data collected at Forest Headquarters some 0.5 km distant.

4.00 MATERIALS AND METHODS

4.10 EXPERIMENTAL DESIGN

The trial is laid out as a 2^2 factorial of nitrogen fertiliser and thinning, replicated three times in randomised blocks.

The analysis of covariance model appears thus:

Source of Variation		df
Blocks		2
Treatments		(3)
Fertiliser	1	
Thinning	1	
F x T	1	
Covariate(s)		1 (+)
Error		5 (-)
Total		11

Formal analysis considers treatment and block effects but three additional aspects of this trial must be considered in interpreting results.

All trees in the experiment were pruned to 1 m above ground level prior to treatment. Published information on a pruning lift of this severity (less than 20% mean tree height) suggests the associated increment loss to be small (Sutton and Crowe, 1975). The alternate deep and shallow ripping carried out prior to establishment must also be considered in interpreting results. Deep ripping (1.20 m) has at least partially fractured the fragipan, while shallow ripping (0.45 m) may or may not. Section 5.20 presents data evaluating the affect of ripping upon initial tree height and diameter and upon basal area increment from age 7 to 9. The full import of ripping, however, is not formally catered for in the experimental design or analysis.

Thirdly, all trial results must be interpreted in the light of a basal dressing, of copper and phosphate applied to the entire trial area. Copper superphosphate, at 5 and 75 kg ha^{-1} of C and P respectively, was hand applied in September 1977. The copper was added to maintain good stem form and the phosphate to ensure P levels would not limit response to N. The addition of these nutrients do not influence the statistical measurement of nitrogen response.

The four treatments in this trial represent two factors, fertilisation and thinning, each at two levels, present or absent. Thinning levels were defined as: (1) no thinning - retention of original plot stocking of 1680 stems ha^{-1}, and (2) a 50% basal area reduction from the original stocking level.

The thinning criteria, in order of importance were: (1) reduction of basal area by 50% of that present in June 1977, (2) selection of residual trees of good form and dominance class, and (3) distribution of the residual stems in as regular a spatial pattern as (1) and (2) would permit.

A "paper-thinning" was carried out, checked in the field, and the stand thinned to waste on September 22, 1977. Trees were identified as either "thinned" trees or crop trees. Subsequent analysis of response is primarily concerned with the crop tree element. The plot basal area reductions are given in Appendix 5 and average 46.5%.

Fertiliser was applied at two levels: (1) no fertiliser, and (2) application of 400 kg ha^{-1} of ammonium sulphate in a split dressing on September 20, 1977 and November 14, 1977. Fertiliser was hand distributed over quadrats of known area within each fertilised plot. Quadrats were covered twice with one half the application rate to minimise distribution errors.

Eyrewell weather station records show 0.5 mm of rain on the first day of fertiliser application, followed by 12.4 mm in the succeeding 48 hour period. Mean daily maximum temperature for the week following September 20, 1977 was 13.6°C. Eyrewell weather records indicate 6.9 mm of rain fell on the day of the second dressing, followed by 3.0 mm of additional precipitation in the 9 day period following. Mean daily maximum temperature for the week November 14 to 21, 1977 was 18.4°C.

Conditions following fertilisation suggest that N losses through volatilisation can be expected to be small.

The four treatments: control, fertilised, thinned, and fertilised and thinned are abbreviated to: Cont. or C; Fert. or F; Thin. or T; and Fert + Thinned or F + T in the tables, figures and appendices.

4.20 DATA HANDLING AND ANALYTICAL PROCEDURES

Field measurements were coded directly onto computer forms on all measurement occasions. Data subsequently derived from laboratory procedures were added to the original field-sheets. Primary data processing was carried out on the University of Canterbury Burroughs B6718. A variety of scanning programmes were used in an attempt to identify outlying measurements. Data points lying beyond two standard deviations of the mean were checked for coding or punching errors. Corrections were made if possible and in the case of large data sets, if no objective correction could be made, data were excluded from further analysis.

Regressions were calculated using a Burroughs utility (BASIS) which fitted a simple linear regression model.

Analysis of covariance (Ancova), to compare regression lines on large data sets, was carried out using dummy variables and calculated using a BMD-02R step-wise regression package.

Ancova at the plot level, to test for differences between regression lines, was carried out by either manually calculating separate and pooled regressions on a PDP-8 digital computer or by TEDDYBEAR, a statistical programme written by J.B. Wilson of Otago University, New Zealand.

Duncans' New Multiple Range Test was used to test treatment means (Steel and Torrie, 1960).

Analytical procedures carried six or more significant digits but for the purposes of presentation space permits the inclusion of only two or three decimal places.

The probability levels and abbreviations used throughout are: P = 0.10%, + ; P = 0.05%, *; P = 0.01%, ** and; P = 0.001%, ***.

4.30 PRIMARY DATA COLLECTION

Biomass is defined following Ozlanyi (1977) as the total amount of functionally live tissue of the tree species under consideration. The definition is further constrained, in this study, by consideration of above ground material only.

The term crown refers to the live crown only and is given to mean all above-ground branch material originating from the main-stem. Stem cones, stem needles and litter suspended in the crown are not included in total crown weight.

The crown is further divided into: (1) crown foliar or needle weights, which includes all green and apparently active branch foliage, and (2) crown wood weight, which includes branch wood, bark and buds. These divisions approximate productive and non-productive or supportive categories.

It is desirable to include stem needle weight in the productive category as its mass may be considerable. However, as no acceptable method of predicting stem needle weight was found, using non-destructive measurements, this component was excluded in order to allow direct comparison of measured and predicted crown weights.

Tree total weight is given as the sum of component weights above a 0.05 m stump. This includes total crown weight, the weight of dead branches, stem cones and needles, and stem wood + bark weight.

Individual branch weight components follow the same productive and non-productive categories defined for the crown. Branch total weight is given by the sum of foliar and wood weight + reproductive structures and dead needles.

It was necessary for sampling purposes to define a branch as distinct from a flushing bud. Branch status was achieved when the scarious bracts no longer covered the emerging needles. Branches were considered alive if supporting green foliage.

All weights reported in the study are oven-dry weights. Biomass components were dried at 65-80°C in forced-air ovens for consistent lengths of time. Weight loss over a 24 hour period was used as a check. Branch diameters were measured with vernier calipers to the nearest 0.1 mm, across the minor axis in a plane perpendicular to the main stem, an estimated 25 mm from the stem. Branch lengths were measured with a tape to the nearest 10 mm, following the major axis of the branch to the dominant tip.

Crown position is defined in relationship to the annual shoot stem units. Each polycyclic annual shoot has two crown positions; the first defined at the height of the basal or first cycle branch cluster (designated throughout the study by the year of annual shoot and a +, e.g. 1973+). The second position is defined at the mean cluster height of the remaining cycles and includes all remaining branch clusters in the annual shoot. This division is designated by the year of the annual shoot and a - , e.g. 1973-.

4.31 Data source 1 (DS1)

Data in this section originate from a non-destructive measurement system. Matched samples of trees were monitored for bole and branch diameter response over the two year period following treatment. In the first year measurements were taken at monthly intervals, excluding the winter period, and in the second year at 6 monthly intervals.

During the first year plot sample trees were subject to random partial replacement every 3 months. A replacement sampling scheme was chosen initially as: (1) individual tree measurements were time-consuming and thus sample numbers restricted, and (2) because partial replacement sampling may give more precise estimates of the current mean than measurements of a completely matched sample of the same size.

It was found that the replacement sample size was not sufficiently large to make effective use of the sampling technique and, as estimates of change assumed primary importance in the study, the data were modified to represent a series of matched samples between adjacent times. The estimates of change derived from matched samples are more precise than those from a partially replaced sample of the same size, although they may be less accurate.

Annual measurements were made in October 1977, 1978 and 1979 upon a permanently matched sample of 12 trees per treatment. The measurements of stem and branch diameters were used in conjunction with DS3 regressions to estimate annual changes in foliar weight production and distribution.

Tree measurements included stem diameter (d), sectional measurements as described for annual shoot stem volume calculations (Section 4.33), total tree height, branch cluster heights and an enumeration of all branch diameters.

4.32 Data source 2 (DS2)

In June 1977, 1978 and 1979 stand measurements were taken in which the diameters of all inner plot trees were measured with diameter tapes at marked points. In 1977 all outer plot trees were similarly measured. The heights of all inner plot trees were measured to the nearest 0.05 m in June 1977 with height poles. A sample of 10 trees, selected from the diameter range, was re-measured in June 1978 and 1979. Qualitative descriptions of general tree form and dominance class were made in 1977 and 1979.

All mensurational data were recorded in association with codes identifying treatment, deep or shallow rip status and crop or thinned tree designation.

4.33 <u>Data source 3</u> (DS3)

Above ground full-tree biomass samples were taken in August 1977, 1978 and 1979. Sample trees were randomly selected to represent the diameter range. Trees were cut at 0.05 m height above ground and lowered onto a tarpaulin for transport to the laboratory.

Twelve sample trees were selected in 1977 (pre-treatment) and 24 (6 per treatment) in 1978 and 1979. The sample trees were chosen from the inner plots of the two thinned treatments in 1977 and from the plot surrounds of all treatments in 1978 and 1979.

The measurements recorded each year were: total tree height, diameter at breast height (d), height to branch clusters, branch numbers, diameters, lengths, foliar weight, wood weight and total weight. Mean branch angle was measured on the basal cluster of each annual shoot in 1977 and 1978 as illustrated in Figure 2.

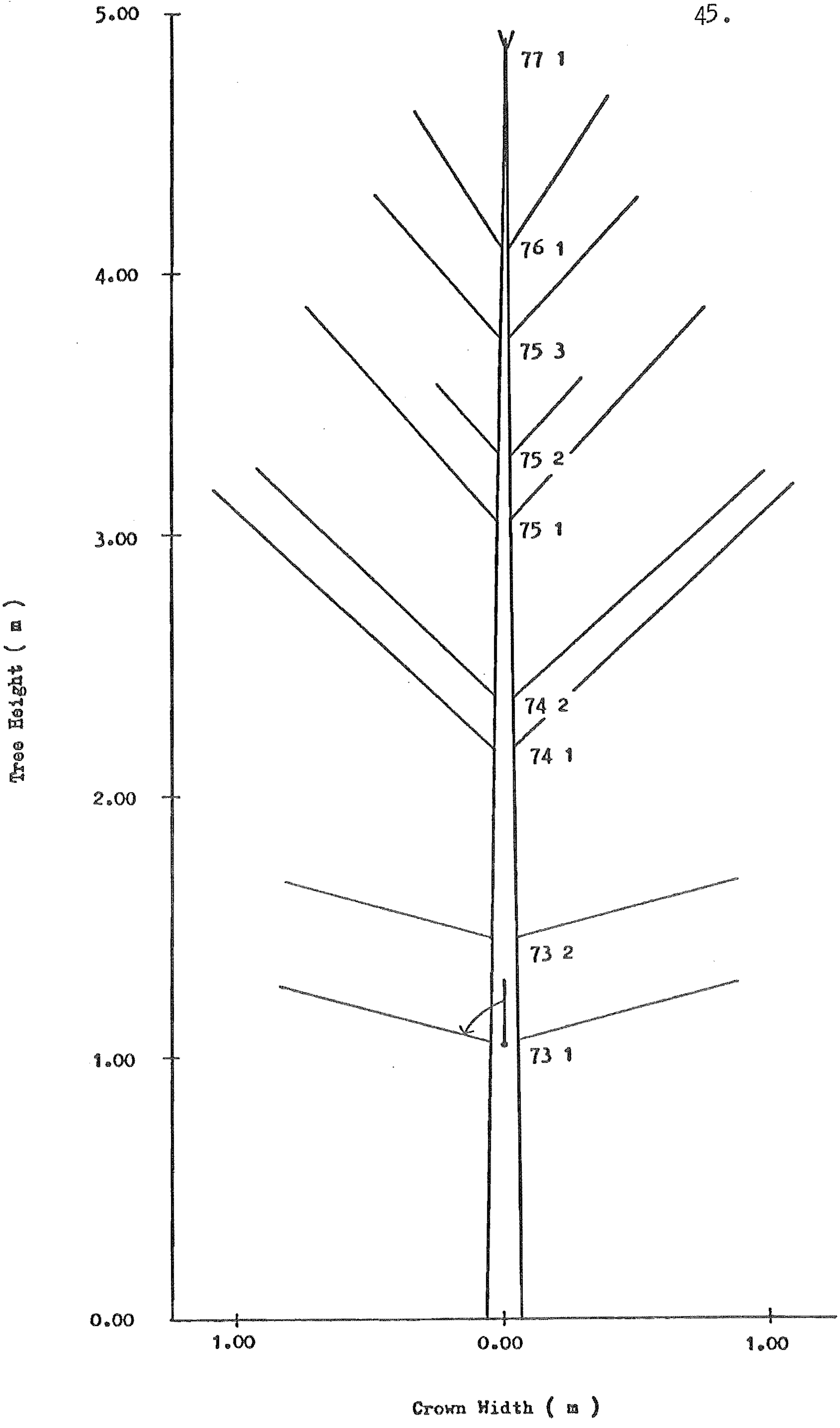


Figure 2. Diagramatic representation of a tree showing crown positions and terminology of ageing. August 1977.

Two series of stem sectional measurements were made for the calculation of volume. The first method, called internodal volumes, required total tree height and sectional measurements (o.b.) taken at stem base (0.06 m) and at mid-internode or every 1 m height. At each measurement point four bark thickness measurements were taken at 90° angles. The second series of volume measurements, called annual shoot volumes, consist of total tree height, and stem sectional measurements (o.b.) at stem base and immediately below the nodal swelling at each annual shoot. Both series of measurements were processed by the same programme to calculate volumes from a conic integral formula (Whyte, 1974).

In 1977 the stem wood fraction was dried without sub-sampling. In 1978 and 1979 discs were sub-sampled from the stem and total weights calculated from the dried sub-sample and known green weights.

4.34 Data source 4 (DS4)

Measurement of four branch variables were made at 3-monthly intervals between August 1977 and August 1978. These data were used to construct equations predicting branch length, foliar weight, wood weight and total weight from branch diameter.

The branch biomass measurements were consistent with branch data collected on full-tree biomass occasions. Sample branches were, therefore, classified according to time of sample, treatment, and crown position.

Branches were selected from the surround trees of each plot following a systematic sampling scheme whereby a maximum of 1 branch per tree per sampling occasion was taken. Sampling was initiated at a randomly selected tree number and followed the tree numbering system. Trees bordering windrows, adjacent plots or inner measurement plots were excluded, as were trees near rainfall collectors or litter traps.

A minimum of five branches per plot and crown position were taken, giving a total of 15 branches for a treatment regression. Ocular estimates of branch length were used in selecting samples to give as wide a diameter range as possible.

Branch diameters and lengths were measured in the field. The samples were then labelled and returned to the laboratory for oven-dried weight determination.

5.00 PRIMARY DATA PRESENTATION AND ANALYSIS

5.10 DATA SOURCE 1 (DS1)

Sample tree branch and stem diameter measurements have two uses as given in the methodological flowchart (Figure 1). Repeated measurements of branch diameters of individual trees provide the independent variable in equations predicting crown biomass components. Secondly, the repeated measurements of stem diameters are used to evaluate volume response (o.b.) and stem profile development.

Data source 1 provides information on tree dimensional changes at monthly intervals throughout the first year (Appendix 6). The influence of treatments upon diameter and volume increment is confined to the magnitude of response at a given time. There is no indication of a lag-time. This generalisation appears to hold true in the first year of height increment, but is less clear in the second year.

Increment patterns at Eyrewell show a consistent minimum increment in the January-February-March period. This effect is interpreted as a result of summer droughting and can also be seen in branch diameter increments (Appendix 7).

Branch diameter increments, in the first year, and two year period following treatment showed, with a single exception no treatment interaction (Tables 2,3). Thinning tended to increase branch diameters at the crown base, whereas fertiliser responses were greatest at mid and upper crown.

Table 2: Summary of treatment mean branch diameter increment Anovas. October 77 to October 78. Range test at P = 0.05.

Annual shoot	Treatment Means (mm)				Interaction
1973	C 0.79	F 0.81	T 1.69	F+T 3.07	*
1974	C 1.35	F 2.10	T 3.03	F+T 3.81	ns
1975	C 2.71	T 3.89	F 4.02	F+T 5.63	ns
1976	T 2.76	C 3.54	F+T 5.31	F 5.83	ns
1977	F 1.77	C 1.88	T 2.50	F+T 4.67	ns

Table 3: Summary of treatment mean branch diameter increment Anovas. October 77 to October 79. Range test at P = 0.05.

Annual shoot	Treatment Means (mm)				Interaction
1973	C 0.52	F 1.23	T 1.92	F+T 3.65	ns
1974	C 1.76	F 2.64	T 4.02	F+T 4.97	ns
1975	C 3.72	F 5.58	T 5.86	F+T 8.37	ns
1976	T 5.22	C 5.76	F+T 9.37	F 9.97	ns
1977	C 3.38	T 4.29	F 5.78	F+T 9.63	ns

The summaries of treatment mean branch diameter analyses in 1978 and 1979 are given in Tables 4 and 5. In October 1978 no pre-treatment measurements were available at the 1978 annual shoot so Anova was used. In October 1979 the measurements of October 1978 were used as covariates in the 1978 annual shoot analysis as no treatment effects were detected at that time.

Individual tree volume increments were calculated from stem diameter measurements (o.b.) taken in October 1977, 1978 and 1979. First year volume increment was regressed upon initial tree volume and the relationship found to be linear, significant and influenced by treatment (Appendix 8). Ancova indicated that the fertilised and thinned and the thinned treatment slopes were not significantly different, nor were control and fertilised slopes (Appendix 9). The two pooled slopes were significantly different however, and thus the two pooled regression slopes were used to adjust tree volume increments. The Anova of adjusted means is given in Appendix 10.

The same procedure was used to examine the second year increment (October 1978 to October 1979) and the two year increment (October 1977 to October 1979) (Appendix 10).

Relative taper equations for control and the fertilised and thinned data were examined in October 1978 and 1979 to assess possible changes in stem profile development. A programme supplied by R.C.Woollons of NZ Forest Products Ltd was used to test the hypothesis:

$$H_o : \beta_{F+T} = \beta_{Cont.},$$

Table 4: Summary of adjusted treatment mean branch diameter + analyses. October 1978. Range test at P = 0.05.

Annual shoot	Treatment Means (mm)				CV as % Treatment Sum of Squares	Interaction
1973	C 20.2	F 20.2	T 21.1	F+T 22.5	97.9	+
1974	F 20.5	C 20.5	T 21.9	F+T 22.8	98.1	*
1975	C 17.1	T 17.8	F 18.2	F+T 19.8	94.7	ns
1976	T 14.9	C 15.6	F+T 17.7	F 17.7	51.1	ns
1977	F 10.8	C 11.0	T 11.7	F+T 13.7	47.2	ns
1978	T 9.1	C 9.3	F+T 9.5	F 9.6		ns

+ Except for 1978 where no pre-treatment measurements were available, treatment means have been adjusted by Ancova using initial mean diameters as the covariate.

Table 5: Summary of adjusted treatment mean branch diameter analyses. October 1979. Range test at P = 0.05.

Annual shoot	Treatment Means (mm)				CV as % Treatment Sum of Squares	Interaction
1973	C 20.0	F 20.6	T 21.4	F+T 23.0	95	ns
1974	F 20.9	C 21.1	T 22.8	F+T 24.1	96	*
1975	C 18.2	T 19.6	F 19.8	F+T 22.5	89	ns
1976	T 17.5	C 17.8	F+T 21.5	F 21.6	48	ns
1977	T 13.7	C 14.9	F 15.6	F+T 16.0	56	ns
1978	F+T 11.5	C 12.1	T 12.2	F 12.9	17	ns

where β is a vector of regression coefficients. Linear and quadratic models were fitted to the data and the slope coefficients tested for significance. The data would not accept a quadratic term of either integral or non-integral power so the linear model was accepted. The null hypothesis could not be rejected for the data in either October 1978 or October 1979.

Treatment mean tree volume increments, for the first, second and two year period, were significantly affected by treatment but no interaction was detected (Table 6). The thinning main effect was greater in the first year but the fertiliser effect was larger in the second and over the two year period (Appendix 10).

Table 6: Treatment mean tree (adjusted) volume increment o.b. ($m^3 \times 10^{-3}$)
Range test at P = 0.05

Period	Treatment Means (mm)				Interaction
1977-1978 (first year)	C 16.07	F 19.31	T 20.76	F+T 26.11	ns
1978-1979 (second year)	C 18.15	T 23.32	F 25.35	F+T 30.89	ns
1977-1979 (two-year period)	C 33.42	T 44.00	F 45.11	F+T 57.26	ns

The imprecision of over-bark diameter tape stem measurements, may have made interaction effects and stem taper changes difficult to detect.

5.20 DATA SOURCE 2 (DS2)

Stand measurements of diameter and height were used to evaluate stand response to treatment and, in conjunction with DS3 information, to calculate estimates of stand biomass production.

Plot mean tree basal area and height in June 1977 were analysed to evaluate the effectiveness of blocking in the experiment (Appendix 11). Both basal area and height analyses show highly significant block effects. As the random allocation of plots to treatments gave rise to a significant "treatment" effect in plot mean tree height subsequent analyses will be carried out by Ancova.

Individual plot total basal areas ranged from 0.2976 m^2 to 0.4207 m^2. Mean plot (unthinned) basal area was 0.3433 m^2, or 9.156 m^2 ha^{-1} (SE $\pm$ 1.091 m^2 ha^{-1}).

The influence of ripping upon initial plot mean tree height and basal area is examined in Appendix 12. The mean height difference of 0.08 m has a standard error of difference of $\pm$ 0.20 m. Mean tree basal areas differ by 3.75 cm^2 ($SE_{diff.}$ = $\pm$ 1.20 cm^2).

An analysis was carried out to consider the influence of ripping on basal area increment at age 7 to 9 years (Appendix 13). No significant ripping effect was detected. In considering the effect of ripping it should be noted that these analyses represent a single point in time in the development of the stand. No inferences can be made on the influence of ripping at other stand ages. The block-times-ripping interaction was tested to consider the a priori hypothesis that block gradients might be associated with depth of soil to the fragipan and thus have differentially influenced the effectiveness of ripping. The analysis in Appendix 12 did not support this hypothesis as no significant interaction was detected.

Plot mean tree height and basal area increment were analysed for the first and second years following treatment and for the two year period. An end point analysis was carried out in June 1979 on plot mean tree basal area and height (Appendix 14). 1979 plot mean tree heights were adjusted by the regression of 1979 plot mean height (from 10 sample trees per plot) upon 1977 plot mean height. The regression was significant ($P \geq 0.027$), accounted for 66% of within-treatment variation, and was free of treatment effects.

First year and two year mean tree basal area increment showed significant treatment interactions. Height increments did not differ significantly by treatment (Table 7).

5.30 DATA SOURCE 3 (DS3)

The full-time biomass samples satisfied two main requirements in the development of the study methodology. The data provided: (1) the relationship of full-tree biomass component weights to stem diameter, and (2) regressions of the four branch variables upon branch diameter.

The two volume estimates used in this study (Section 4.33) are compared in Appendix 15. The internodal inside bark volumes are given as the best estimate of true volume. The comparison of over-bark internodal and annual shoot volumes are consistent although

Table 7: Summary of plot mean tree height and basal area increment and 1979 height+ and basal area analyses.
Range test at P = 0.05

Plot mean tree basal area increment (cm^2)	Treatment Means				Interaction
June/77–78	C 29.11	F 31.94	T 36.71	F+T 45.21	*
June/78–79	C 33.10	T 45.38	F 47.48	F+T 60.50	ns
June/77–79	C 62.20	F 79.42	T 82.10	F+T 105.71	+
Plot mean tree height increment (cm)					
June/77–78	F 121	C 127	F+T 137	T 137	ns
June/78–79	F+T 139	F 152	T 153	C 167	ns
June/77–79	F 272	F+T 273	T 290	C 295	ns
Plot mean tree basal area (cm^2)					
June/79	C 127.12	F 139.97	T 141.71	F+T 164.68	ns
Plot mean tree height (m)					
June/79	F+T 8.11	F 8.16	T 8.39	C 8.49	ns

+ 1979 treatment means adjusted by Ancova individual trees are wide-ranging. No evidence of a treatment influence in the ratio of bark to wood volume or in the relationship between volume calculation methods was found.

Full-tree regressions of the form,

$$\ln Y = \ln a + b \ln X,$$

were constructed with Y defined in turn as oven-dried total tree weight, total tree branch wood weight, total tree foliar weight and total stem weight. The independent variable was breast height stem diameter squared d^2. No particular significance should be attached to the use of d^2 rather than d as it has been noted that the two are functionally equivalent (Crow, 1971) in the allometric equation. Its use throughout is the result of a computational procedure.

August 1977 pre-treatment regressions were based upon 12 trees (Appendix 16). In August 1978 6 trees per treatment were sampled and separate regressions constructed by treatment (Appendix 17). Ancova procedures tested for significant slope and intercept differences between treatments (Appendix 18). No significant treatment differences were found in any of the four full-tree variables so for predictive purposes the data were pooled.

The August 1979 full-tree regressions were also calculated by treatment (Appendix 19) and examined by Ancova in Appendix 20. No significant treatment differences were found at $P \geq 0.05$ so treatments were pooled for predictive purposes.

Table 8 gives the total tree regressions used in predicting stand total and component weights.

Table 8: Full-tree regression equations used for predictive purposes.

ln Y (kg)	Year	a	b	ln X (cm^2)	RMS	r^2	n
Total tree foliar weight	1977	-3.4335	1.0822	d^2	0.0363	0.901	12
	1978	-3.4252	1.0588	d^2	0.0012	0.856	24
	1979	-3.5651	1.0766	d^2	0.0383	0.820	24
Total tree branch wood weight	1977	-4.5014	1.3069	d^2	0.0211	0.958	12
	1978	-5.5040	1.4859	d^2	0.0396	0.894	24
	1979	-5.4342	1.4583	d^2	0.0457	0.882	24
Total tree stem weight	1977	-2.2476	0.9998	d^2	0.0314	0.890	12
	1978	-2.7283	1.1182	d^2	0.0267	0.877	24
	1979	-2.9192	1.1659	d^2	0.0126	0.946	24
Total tree weight	1977	-2.0145	1.0887	d^2	0.0194	0.939	12
	1978	-2.4068	1.1716	d^2	0.0222	0.916	24
	1979	-2.1472	1.1276	d^2	0.0127	0.942	24

The commitment to full-tree sampling eliminated the possibility of an independent branch sample at these times. Thus, the four branch regressions were derived from the full-tree sample data.

Regressions from this source are subject to two main criticisms. Firstly, Forrest and Ovington (1971) and others have noted that branch relationships differ significantly between clones. It may, therefore, be argued that a small sample of 6 trees per treatment is inadequate for making stand inferences. Secondly, and perhaps more importantly, because each of the 6 trees per treatment has yielded several items of branch data, the lack of statistical independence gives rise to analytical and interpretational problems.

To circumvent this deficiency a frequency distribution of branch diameters was constructed within each treatment and crown position. Branch diameter classes were recognised, within which mean branch diameter, length, wood weight, foliar weight and total weight was calculated. This reduced the degree of freedom of a single crown position from n = 30 to 60 (branches) to n = 7-15 (branch diameter classes) but introduced a measure of independence among data points.

Regressions of the allometric form $\ln Y = \ln a + b \ln X$ were fitted to branch data. Weights measured in preliminary studies were occasionally less than the smallest recorded unit (thus zero weight). As the natural logarithm of 0 is undefined, such measurements caused computational difficulties. For this reason all branch weight raw data had a constant of 1.0 g added before logarithmic transformation. Thus branch weight regressions predict the logarithm of (needle weight + 1.0 g), (branch wood weight + 1.0 g), and (branch total weight + 1.0 g). In transforming predicted logarithmic weights back to arithmetic units the constant was automatically subtracted. Branch length is predicted in cm. The independent variable, branch diameter, is measured in mm. The bias associated with the re-transformation of logarithmic values to arithmetic units was adjusted using Meyer's (1938) published factor:

$$w = e^{\bar{w} + \frac{1}{2}s^2},$$

where: w = corrected weight in arithmetic units,

$\bar{w}$ = estimated weight from regression,

s^2 = residual mean square from regression.

Weights derived from regression are reported in arithmetic units with bias adjusted. The residual mean squares associated with regression are given in logarithmic units.

Branch regressions were calculated for the crown positions represented at time of sampling and analysed as follows: (1) a graphical and quantitative analysis of differences in regression slope and intercept between crown positions, (2) a comparison of basal and non-basal regressions within each annual shoot, and (3) a comparison of regression lines pooled for each annual shoot.

The computational costs of these analyses carried out on three full-tree (DS3) and four branch biomass (DS4) occasions prohibited analysis of all four branch variables. Branch foliar weight was selected as the most important for detailed study and detailed tests were made for this variable only. All analyses were not repeated on all occasions and for reasons of space only the first example of a particular analysis is appended - the rest are summarised in the text.

The branch regressions in August 1977 show a more or less consistent influence of crown position on regression coefficients and residual mean squares from regression (Appendix 21). The foliar weight regressions were graphed (Figure 3) and upon analysis showed significant slope differences between the eight crown positions tested (Appendix 22).

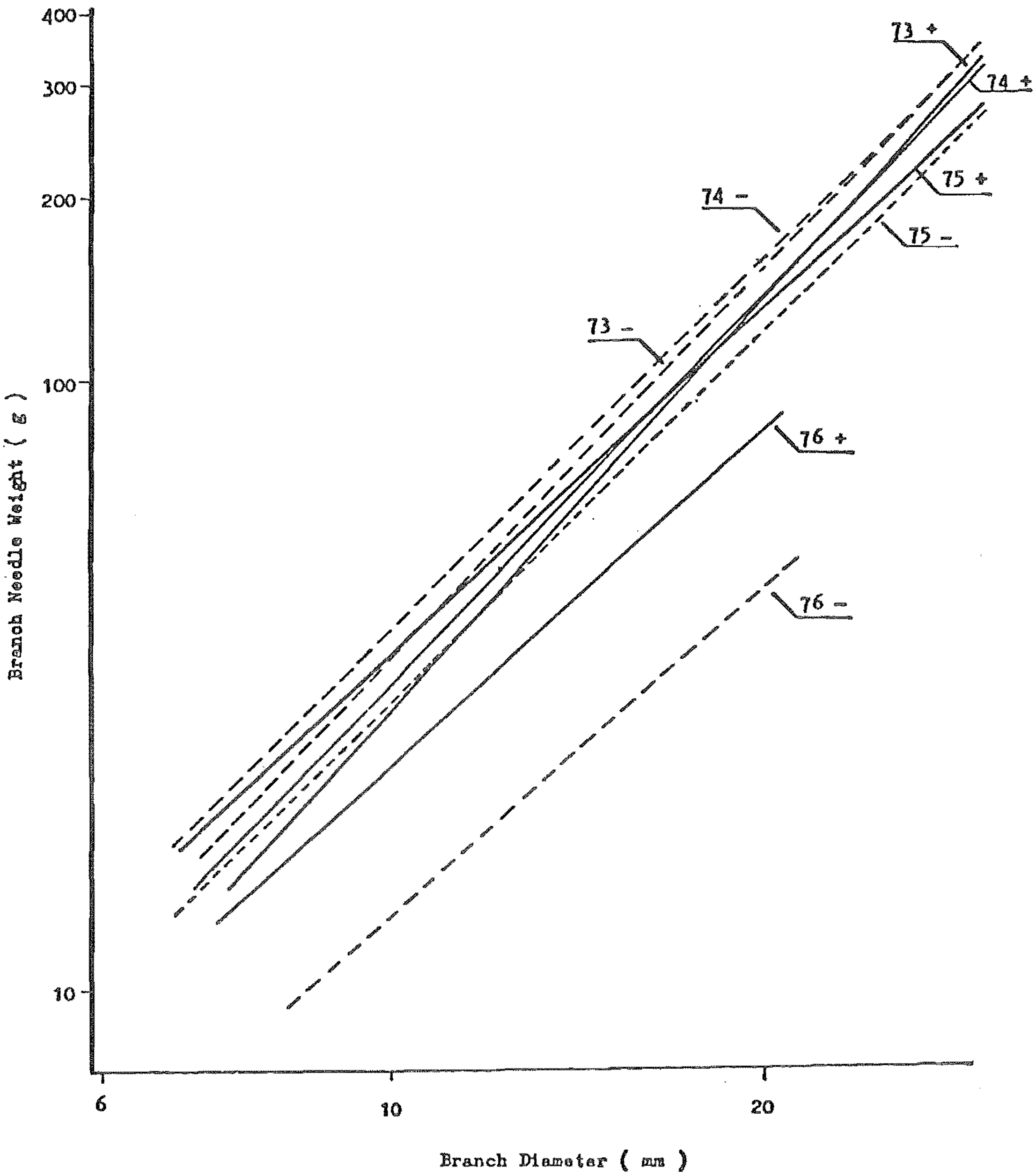


Figure 3. Branch foliar weight regressions.
August 1977. Control treatment.

Basal and non-basal (+, -) divisions were compared within each annual shoot and indicate significant intercept differences in young, upper crown branch material. Intercept differences decrease with increasing branch age (Appendix 23).

Pooled regressions at each annual shoot were compared and significant slope differences found (Appendix 24).

A summary of branch regression analyses is given in Table 9.

Table 9: Summary of 1977 (pre-treatment) branch foliar weight analyses.

Procedure Testing between:		Testing Slopes	Testing Intercepts
8 crown positions		***	
Basal and non-basal clusters at a given annual shoot	1973	ns	ns
	1974	ns	*
	1975	+	**
	1976	ns	***
4 annual shoots (basal and non-basal pooled)		*	

The analyses of branch regressions calculated in 1978 and 1979 (Appendix 25 and 26) are summarised in Tables 10 and 11. The relationship of foliar weight regressions are shown in Figures 4 and 5.

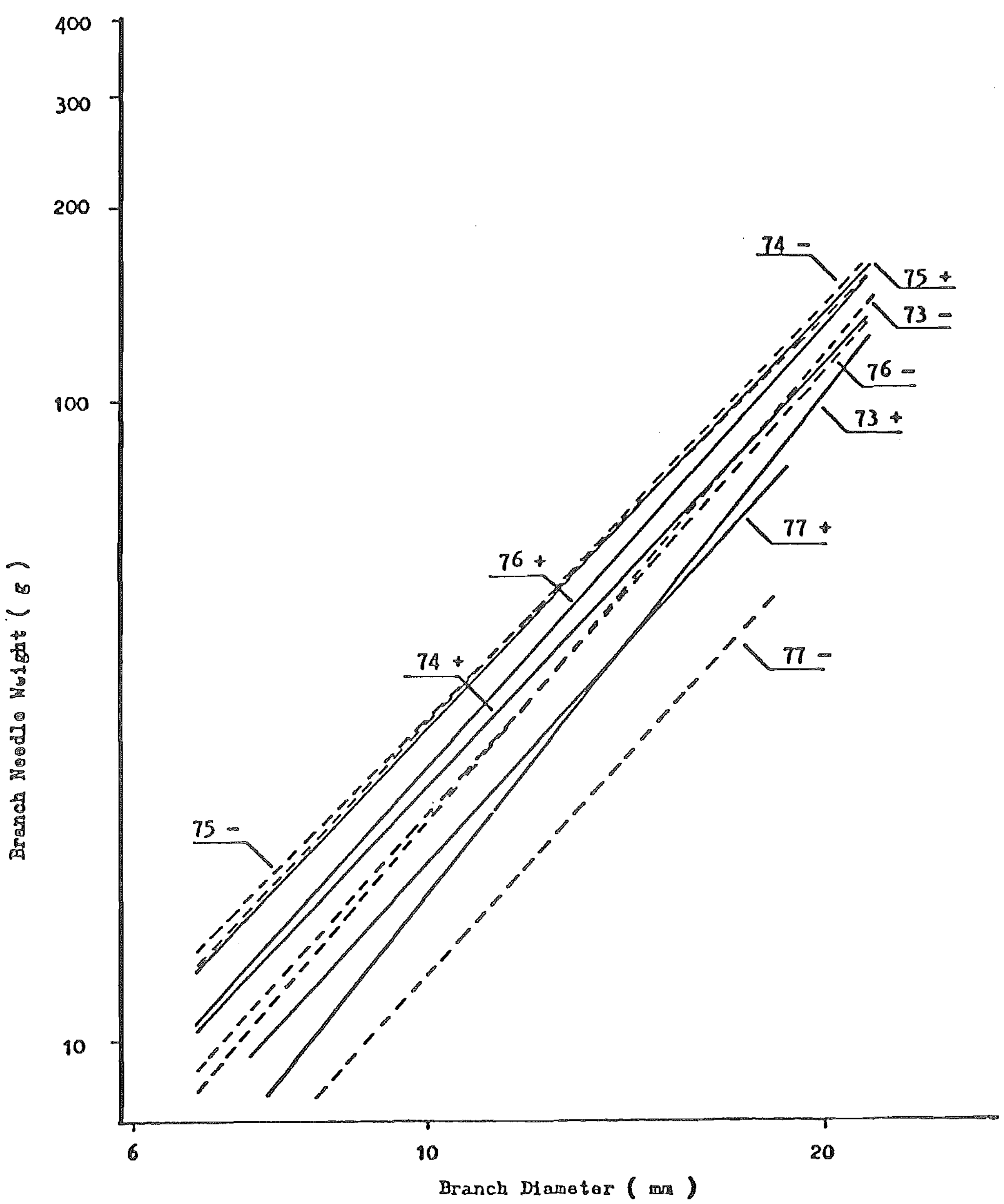


Figure 4. Branch foliar weight regressions. August 1978. Control treatment.

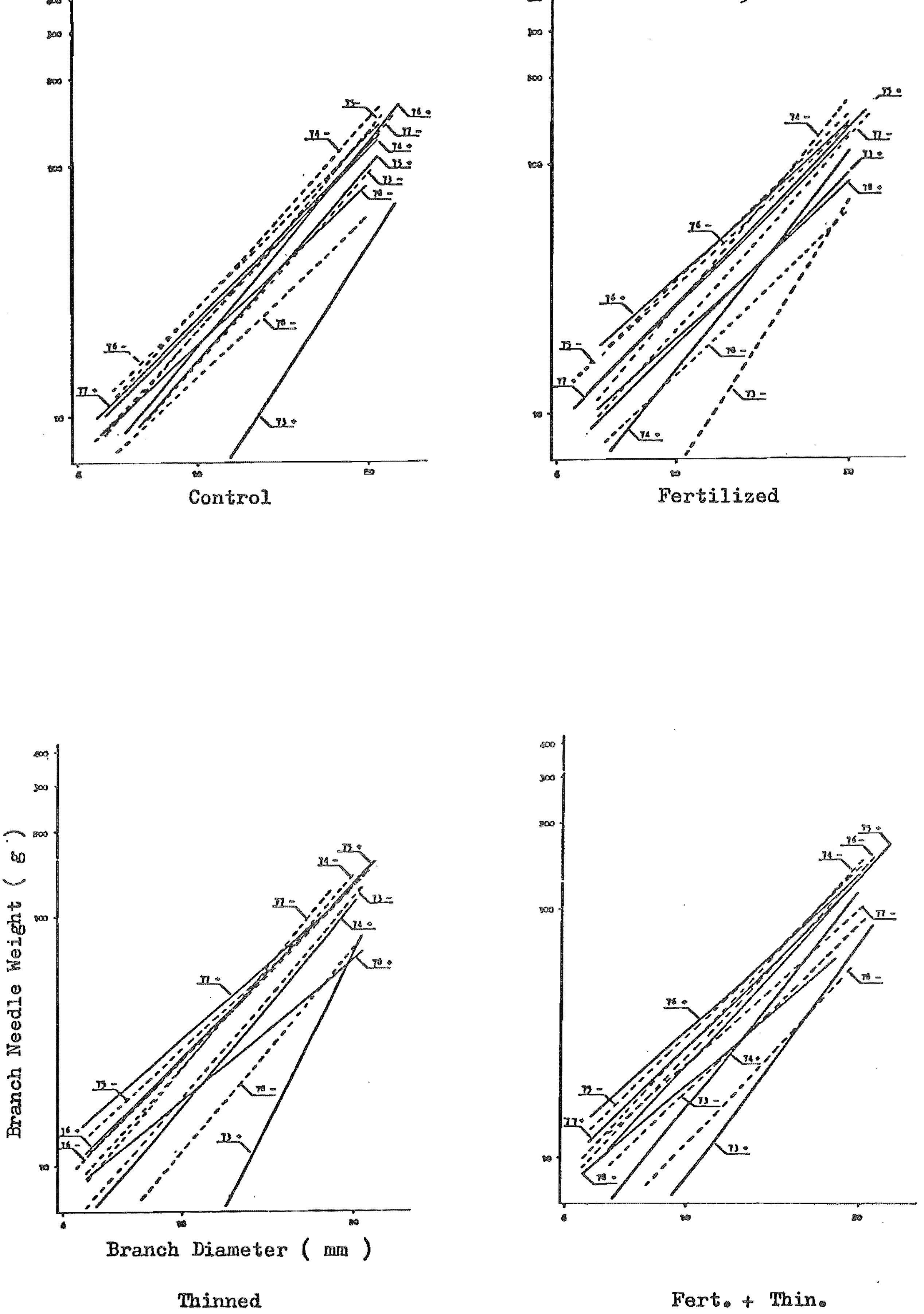


Figure 5. Branch foliar weight regressions.
August 1979.

Table 10: Summary of 1978 branch foliar weight analyses.

Procedure Testing between:		Testing Slopes	Intercepts
10 crown positions	Control	+	***
	Fertilised	*	
	Thinned	***	
	Fert. + Thin.	**	
4 treatments at a given crown position	1973 +	ns	***
	–	**	
	1974 +	ns	*
	–	ns	ns
	1975 +	ns	***
	–	ns	ns
	1976 +	*	
	–	*	
	1977 +	**	
	–	*	

Table 11: Summary of 1979 branch foliar weight analyses.

Procedure Testing between:		Testing Slopes	Intercepts
12 crown positions	Control	***	
	Fertilised	***	
	Thinned	***	
	Fert. + Thin.	***	
4 treatments at a given crown position	1973 +	**	
	–	***	
	1974 +	**	
	–	ns	**
	1975 +	ns	ns
	–	**	
	1976 +	***	
	–	*	
	1977 +	ns	ns
	–	**	
	1978 +	ns	ns
	–	ns	*

The branch regressions calculated in August 1979 show a marked decrease in intercept in the lower crown positions. This effect appears uninfluenced by treatment. In the 18 months between the graphs in Appendix 27 and Appendix 29 the relationship between basal and non-basal regressions altered considerably. This is most apparent in the older annual shoots and appears uninfluenced by treatment.

5.40 DATA SOURCE 4 (DS4)

Branch sampling was carried out to provide estimates of the four branch variable regressions at times between full-tree biomass occasions (DS3). The two data sources, in combination, allowed evaluation of changes in branch regressions over time and between treatments (Table 12).

Table 12: Branch sampling occasions - sample type and time.

Aug/77 Full-tree biomass DS3		Dec/77 Branch biomass DS4		Mar/78 Branch biomass DS4		June/78 Branch biomass DS4
	Aug/78 Full-tree biomass DS3		Mar/79 Branch biomass DS4		Aug/79 Full-tree biomass DS3	

The regressions calculated from branch biomass occasions differ from the full-tree samples in that data points are independent; no two branches in any given sample originate from the same tree. Regressions calculated from these sample branch data were observed to have larger associated error mean squares. This may be an effect of relatively small sample numbers, or because of the pooling of full-tree data into branch diameter classes.

The branch biomass data are presented chronologically: the regression equations are found in Appendices 28, 30, 31 and 32; the foliar weight regressions are graphed in Figures 6, 7, 8 and 9; and the summary of analyses in Tables 13, 15, 16 and 17.

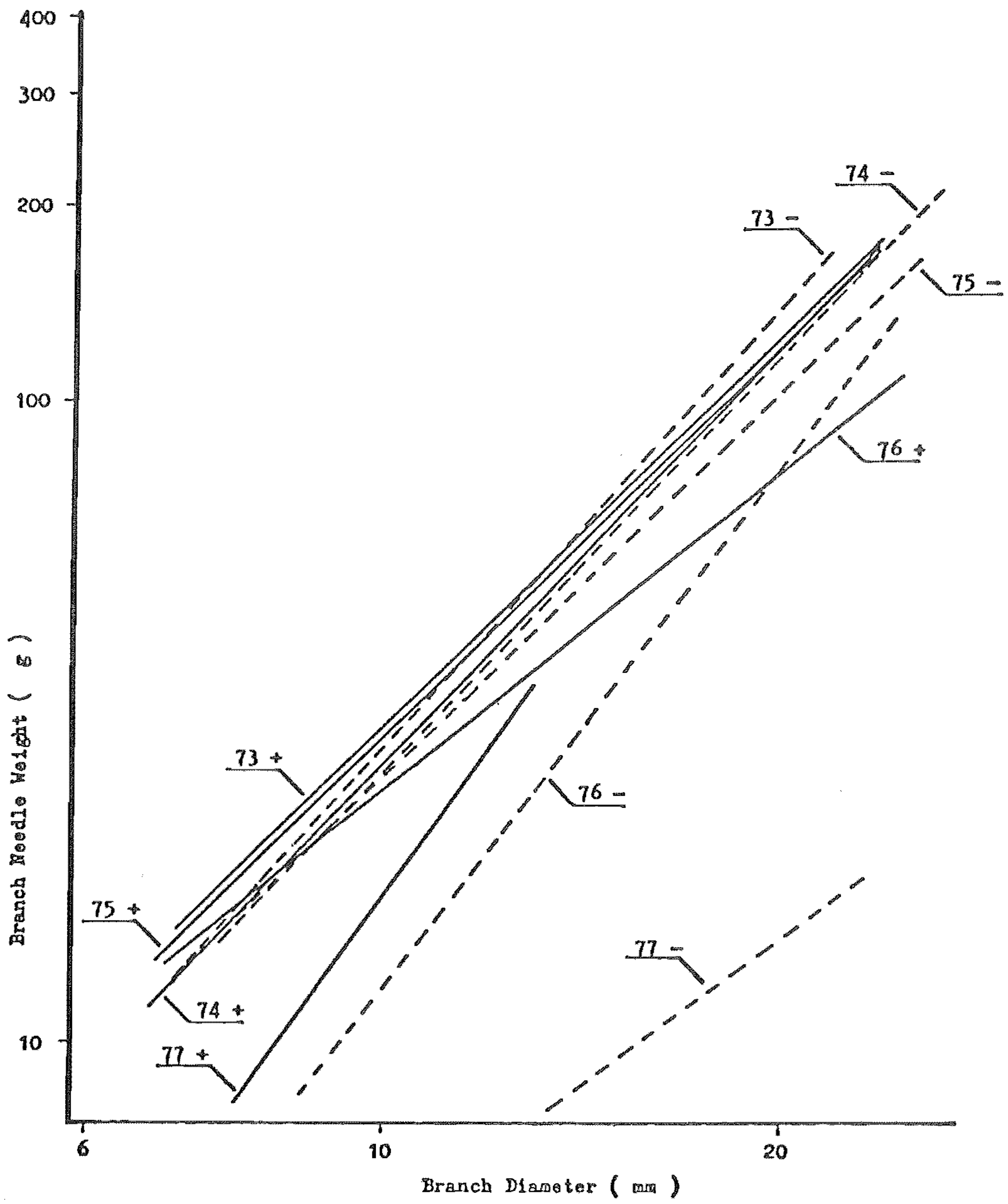


Figure 6. Branch foliar weight regressions. December 1977. Control treatment.

Table 13: Summary of December 1977 branch foliar weight analyses.

Procedure testing between:		Testing Slopes	Testing Intercepts
10 crown positions	Control	***	
	Fertilised	***	
	Thinned	***	
	Fert. + Thin.		***
4 treatments at a common annual shoot	1973	**	
	1974	ns	ns
	1975	ns	ns
	1976	ns	ns
	1977	ns	ns

Table 14: Bracketed numbers the percentage gain in precision, i.e. relative efficiency.

	RMS all data	RMS 1977 excluded	RMS 1976 and 1977 excluded
Control	0.246	0.097 (154)	0.036 (583)
Fertilised	0.240	0.032 (660)	0.037 (549)
Thinned	0.651	0.115 (466)	0.046 (1315)
Fert. + Thin.	0.312	0.093 (236)	0.028 (1014)

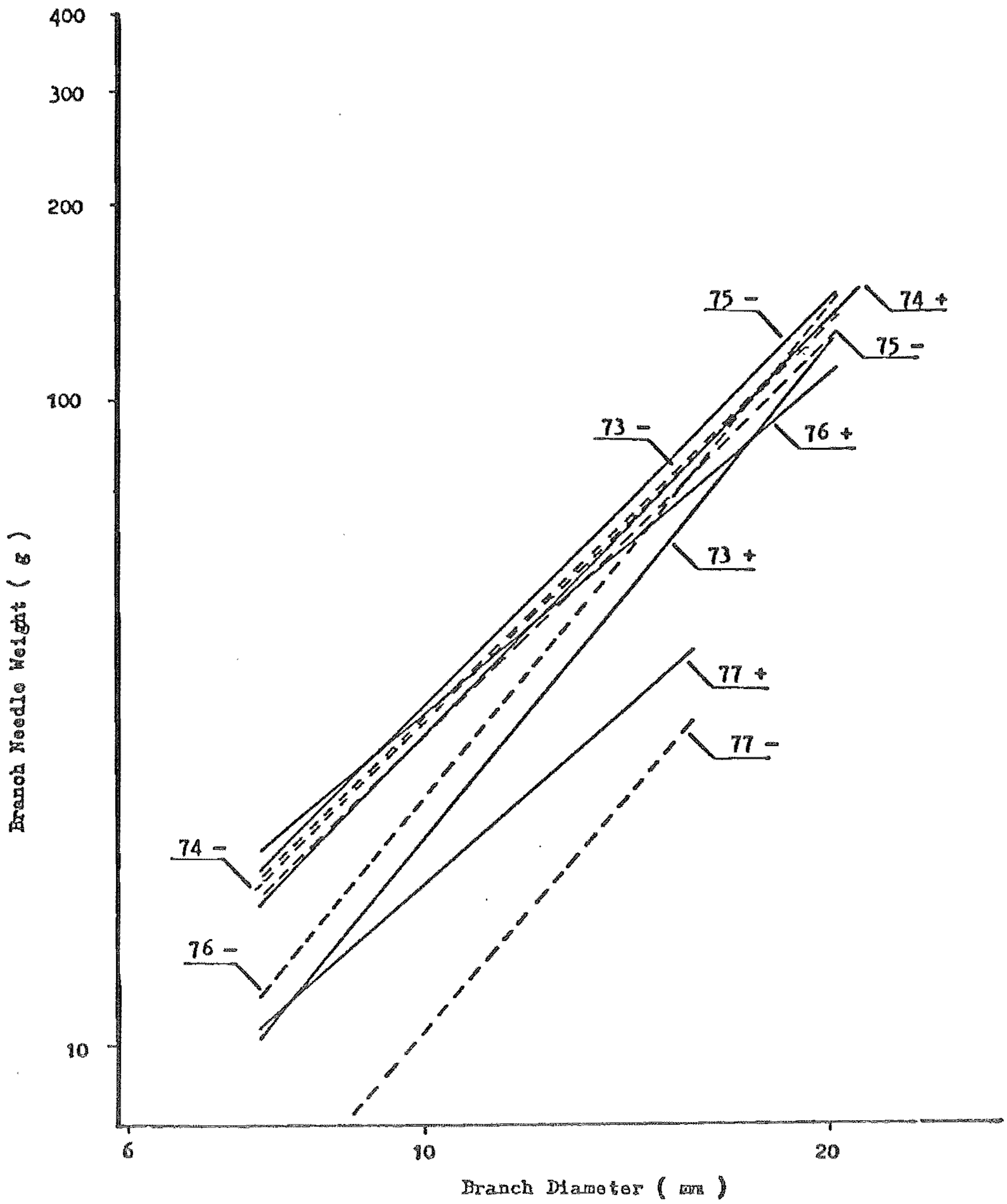


Figure 7. Branch foliar weight regressions. March 1978. Control treatment.

Table 15: Summary of March 1978 branch foliar weight analyses.

Procedure testing between:		Testing Slopes	Testing Intercepts
10 crown positions	Control	*	
	Fertilised	ns	***
	Thinned	*	
	Fert. + Thin.	***	
4 treatments at a common annual shoot	1973	ns	*
	1974	ns	**
	1975	ns	***
	1976	ns	ns
	1977	ns	ns

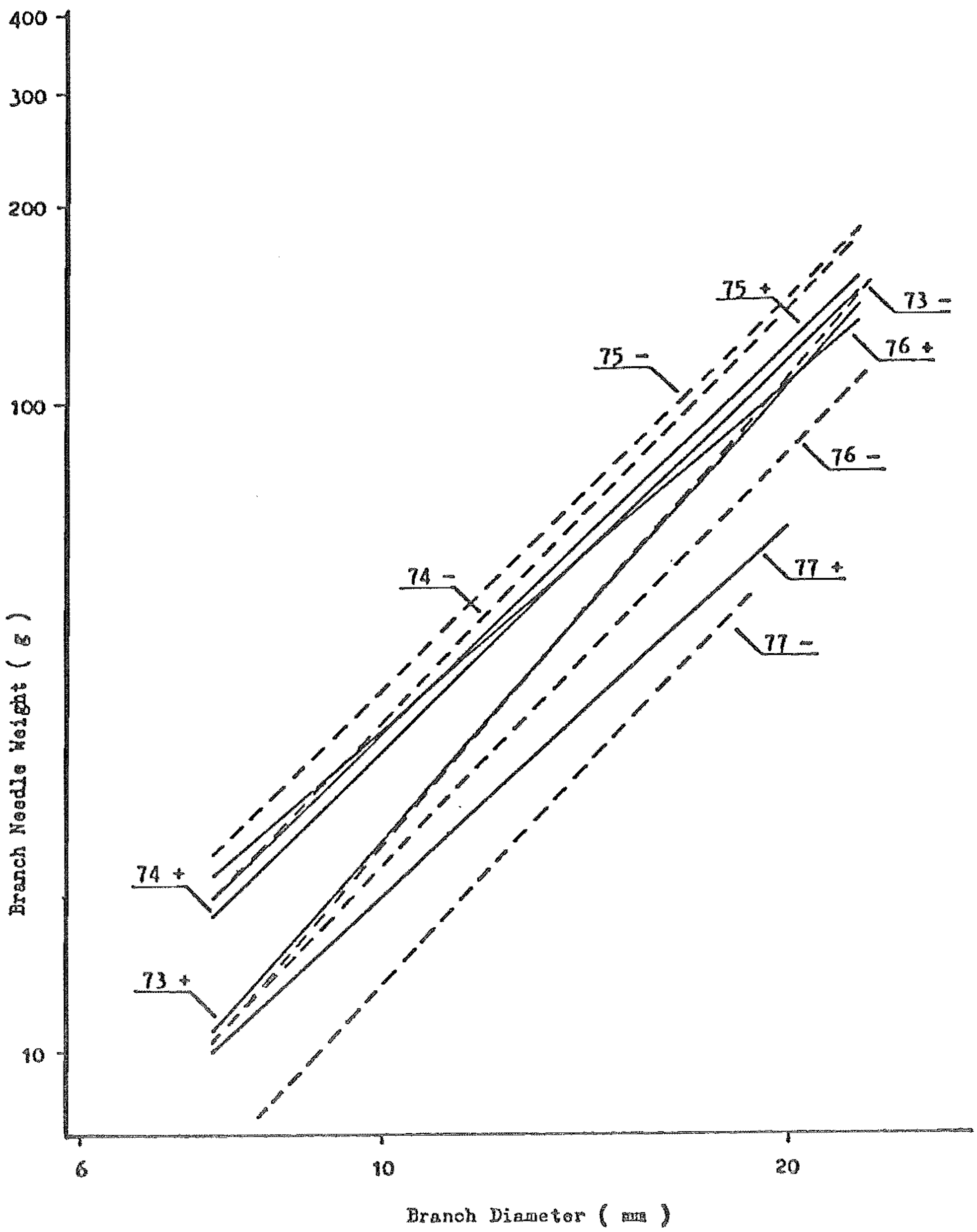


Figure 8. Branch foliar weight regressions. June 1978. Control treatment.

Table 16: Summary of June 1978 branch foliar weight analyses .

Procedure testing between:		Testing Slope	Testing Intercept
10 crown positions	Control	ns	***
	Fertilised	*	
	Thinned	ns	***
	Fert. + Thin.	***	
4 treatments at a common annual shoot	1973	*	
	1974	ns	*
	1975	*	
	1976	ns	ns
	1977	ns	*

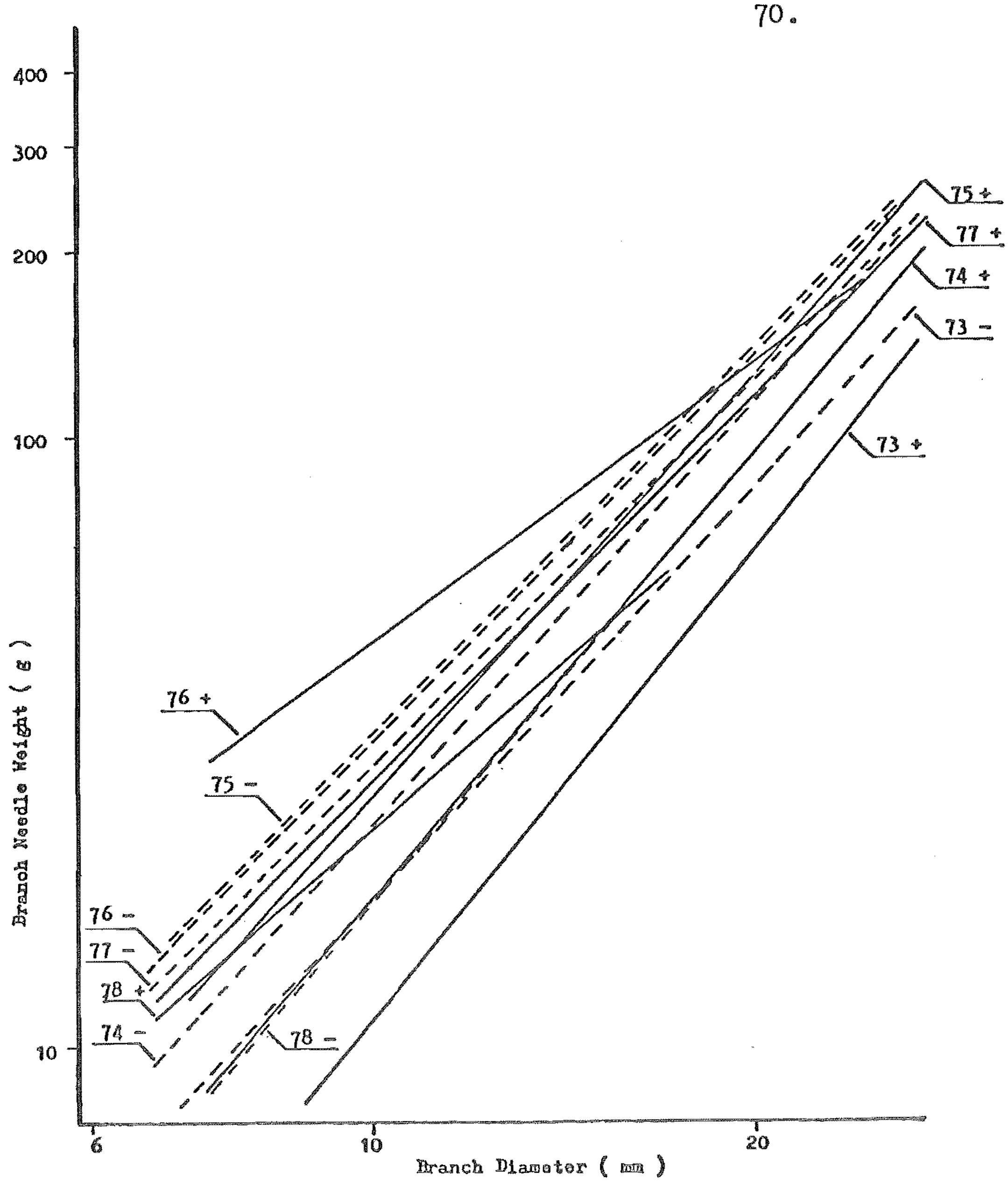


Figure 9. Branch foliar weight regressions. March 1979. Control treatment.

Table 17: Summary of March 1979 branch foliar weight analyses.

Procedure testing between:		Slope	Intercept
12 crown positions	Control	ns	***
	Fertilised	ns	***
	Thinned	*	
	Fert. + Thin.	**	
4 treatments at a given crown position	1973	ns	***
	1974	ns	***
	1975	ns	***
	1976	ns	ns
	1977	ns	+
	1978	***	

The December 1977 data were further examined to determine the gain in precision brought about by the exclusion of particular annual shoot data. The 1976 and 1977 branch data departed most from a common regression. This departure is largely due to intercept differences. The effect of removing first the 1977 and secondly both the 1976 and 1977 branch data results in considerable reductions of residual mean squares from regression. The large gains in precision would appear to justify stratification in the upper crown (Table 14).

Branch biomass data (DS4) and full-tree branch data (DS3) have been considered separately to this point. In analysis of treatment differences at a given time and annual shoot the results are inconsistent. For example 1975 annual shoot analyses for treatment differences showed: (1) no significant effects after 3 months, (2) intercept differences after 6 months, (3) slope differences after 9 months, (4) intercept differences after 1 year, (5) no significant effect after 18 months and (6) no effects after 2 years (Table 18). Indications of treatment effects are generally limited to the lower crown but whether this effect is real or a result of relatively greater sample variation in the upper crown is not known.

In examining branch data for time effects the two treatments considered, control and fertilised and thinned, were tested separately at given annual shoots (Table 19). For the control this represents a test over time but results from the fertilised and thinned data are confounded with the effects of treatment.

Table 18: Summary of treatment effects in all foliar weight analyses.

Time	Annual shoot	Testing Slope	Testing Intercept
Aug/77 - no treatments			
Dec/77	1973	**	
	1974	ns	ns
	1975	ns	ns
	1976	ns	ns
	1977	ns	ns
Mar/78	1973	ns	*
	1974	ns	**
	1975	ns	***
	1976	ns	ns
	1977	ns	ns
June/78	1973	*	
	1974	ns	*
	1975	*	
	1976	ns	ns
	1977	ns	*
Aug/78	1973	ns	***
	1974	ns	**
	1975	ns	*
	1976	ns	ns
	1977	ns	ns
Mar/79	1973	ns	
	1974	ns	+
	1975	ns	ns
	1976	ns	***
	1977	ns	***
	1978	***	***
Aug/79	1973	+	**
	1974	ns	*
	1975	ns	ns
	1976	***	
	1977	ns	ns
	1978	ns	ns

Control results at all annual shoots show no significant ($P = 0.05$) slope differences but highly significant differences in intercepts. The combined treatment showed slope differences in the mid and lower crown and intercept differences at all other annual shoots, (Table 19).

Table 19: Summary of time and time-treatment effects upon branch foliar weight regressions.

Procedure testing between:		Testing Slopes	Intercepts
5 sampling times			
(Control treatment)	1973	ns	***
	1974	ns	**
	1975	+	***
	1976	ns	***
5 sampling times			
(Fert. + Thin.	1973	*	
treatment)	1974	ns	***
	1975	*	
	1976	ns	***

The influence of the different regression coefficients over time and between treatment were considered further. A model tree was simulated to represent an "average tree" as sampled in the August 1977 full-tree biomass. Eight crown positions from 1973 to 1976 were assumed and the same diameter range of hypothetical branches assigned to each. This range did not exceed that range known to exist at any of the crown positions.

Time effects were simulated by successively calling the predictive branch regressions calculated over the first year of treatment. The predicted foliar weights by treatment were thus free from the effect of changing (or differentially changing) branch diameters (Figure 10).

Differences in time are not obvious; in the control treatment the predicted weights of the lowest crown position decrease in magnitude over time. In the upper crown this trend is reversed with predicted branch foliar weights increasing with time. The upper crown of the fertilised and thinned treatment responded as the control. At the lowest crown position however, the regular decline in predicted foliar weight seen in the control is not present. Predicted weight decreased initially but then behaved erratically. Mid-crown positions show no obvious trends. The range of results indicate that treatment differences in regression coefficients are relatively small and inconsistent. This was anticipated as the analyses of branch regressions showed irregular treatment differences.

The results obtained from testing branch equations for crown position, treatment and time differences were inconsistent and largely unsatisfactory. It was necessary, however, that a decision be made on pooling for predictive purposes. Although vigorous justification is lacking the decision was made not to pool data by crown position, treatment or over time. The reasons for this were two-fold.

Firstly, one of the goals in this study was to evaluate possible gains in predictive precision through crown stratification. While it has not been possible to justify the significance of each

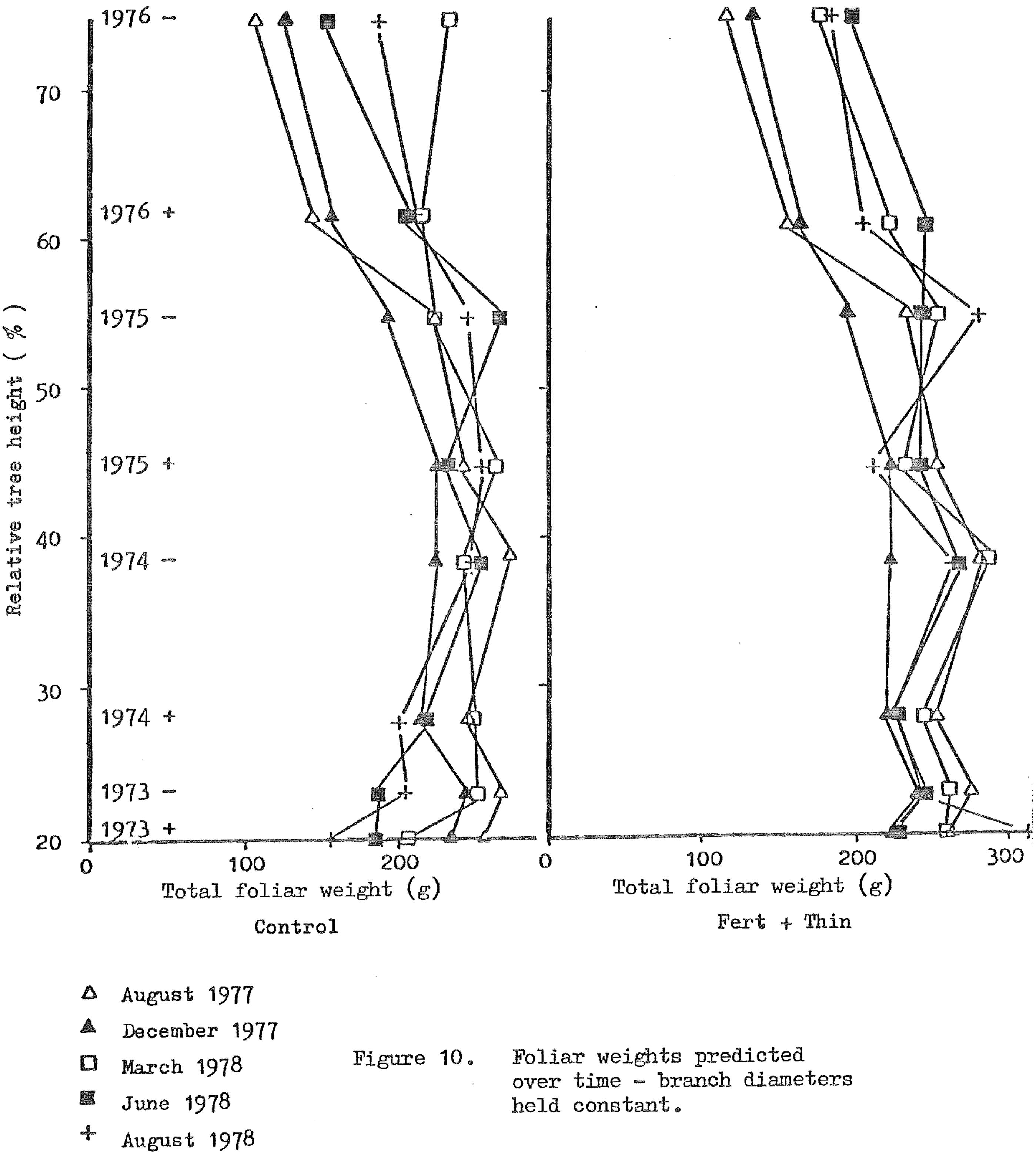


Figure 10. Foliar weights predicted over time - branch diameters held constant.

crown position there is evidence of factor(s) consistently affecting crown position response. Analysis has shown significant effects at the extreme crown positions only, but to assume, therefore that the rest of the crown is homogenous places considerable faith in the ability of the analytical techniques. Secondly, the gain in predictive precision associated with pooling data is not large; the lack of fit in individual regression lines (especially those from pooled full-tree data) does not appear to arise primarily as a result of limited amounts of data.

6.00 INTEGRATING DATA SOURCES

This section integrates the four data sources which, until now, had been considered separately. Figure 1 shows that combination of these data gives: (1) annual estimates of stand biomass production (Section 6.10), and (2) annual estimates of individual tree crown biomass (Section 6.20).

6.10 ANNUAL ESTIMATE OF STAND BIOMASS

Total stand biomass and component biomass weights were calculated by the summation of predicted individual tree weights on a per hectare basis. Bias associated with logarithmic transformation was adjusted. A pre-treatment estimate (Table 20) was made using tree diameters measured in June, 1977 and August 1977 regressions (Table 8).

TABLE 20: Pre-treatment stand biomass accumulation. June 1977 (tonnes ha^{-1}). Crop tree element.

	Total tree weight	Total tree needle weight	Total tree branch wood + bark weight	Total tree stem wood + bark weight
All trees	23.04	5.46	4.98	12.43
Crop trees	12.32	2.92	2.67	6.61
Thinned trees	10.75	2.55	2.31	5.79

In this pre-treatment estimate total weight was composed of 54% stem + bark, 22% branch wood and 24% foliar weight. This closely corresponds to the figures of 50%, 20% and 30% given for the same components by Baker et al. (1974) in reference to a 6 year old stand of fertilised loblolly pine.

Estimates of stand biomass in June, 1978 (Table 21) were made from June 1978 measured diameters and pooled August 1978 regressions (Table 8).

TABLE 21. Adjusted estimate of stand biomass accumulation. June 1978 (tonnes ha^{-1}). Crop tree element.

	Total tree weight	Total tree needle weight	Total tree branch wood + bark weight	Total tree stem wood + bark weight
Control	18.70	3.88	3.90	10.50
Fertilised	19.64	4.07	4.11	11.03
Thinned	20.88	4.32	4.39	11.71
Fert. + Thin.	23.14	4.73	5.03	12.91

Ancova was used to adjust plot biomass estimates based upon observed differences in initial plot total basal area (Appendix 5). Initial sum of plot basal area was found to be linearly related to predicted plot biomass estimates and free of treatment effects. The covariate, as used for total tree weight, tree needle weight, tree branch wood weight, and tree stem wood weight analyses accounted for 88% ($P = 0.02$), 84% ($P = 0.03$), 92% ($P = 0.02$) and 85% ($P = 0.03$) of within-treatment sum of squares respectively.

After adjustment treatment means showed significant differences and treatment interactions were detected in all component and total biomass weights (Appendix 33). The order of response was control, fertilised, thinned, and fertilised plus thinned.

Stand biomass production for all stems (calculated as the mean of the six unthinned plots) was 35.67, 7.42, 7.39 and 20.06 tonnes ha^{-1} for total tree, needle weight, branch wood weight and stem + bark weight respectively.

June 1979 stand biomass estimates were calculated as described in 1978. The covariate was tested for treatment effects and found to be non-significant. Crop tree biomass two years after treatment (Table 22) showed significant treatment effects in all components but a significant interaction was detected for branch wood weight alone (Appendix 34).

TABLE 22: Adjusted estimate of stand biomass accumulation. June 1979. (tonnes ha^{-1}) Crop tree element.

	Total tree weight	Total tree needle weight	Total tree branch wood + bark weight	Total tree stem wood + bark weight
Control	27.25	5.15	5.75	15.31
Fertilised	32.56	6.11	6.96	18.38
Thinned	33.57	6.31	6.65	18.95
Fert. + Thin.	40.00	7.46	9.02	22.73

Estimates of stand biomass in the literature are numerous but those presented in Table 1 have been selected as the most appropriate for comparison with this study. The data in Tables 20, 21 and 22 have been calculated on the crop tree element. Reported biomass per hectare would obviously be higher if all stems in the unthinned plots were considered; however, this was not done in order to preserve comparability between treatments.

The 1977, 1978 and 1979 estimates are given at stand ages 7, 8, and 9, at a density of c. 900 stems ha^{-1}, and treatment mean basal areas of 4.85, 7.70 and 11.40 $m^2 ha^{-1}$ respectively.

It is apparent that stand biomass production is less than that reported on the Australian and North Island sites (Table 1). The differences are explicable when the site qualities are compared. Madgwick et al. (1977) estimated the site index of the Kaingaroa plots at 36 m height by age 20. In Canterbury 21 m at the same age is expected (D.J. Mead, pers. comm., 1979).

No site index was given for the Tamut site but, after comparison with Eyrewell, the site productivity of the former was estimated to be considerably higher (K.R. Shepherd, pers. comm., 1979).

The estimate of 42.20 tonnes ha^{-1} for a 9 year old stand of 12.3 $m^2 ha^{-1}$ basal area in Kaingaroa may be compared with the thinned treatment of this study at age 9 and mean basal area of 12.4 $m^2 ha^{-1}$ (Table 22). Total production was 13% greater on the Kaingaroa site which was stocked with fewer but larger stems.

After two years of treatment the proportions of biomass components were 58% stem + bark, 22% branch wood and 20% foliage (Table 22). There is essentially no treatment differences in these proportions of biomass components as they were calculated from full-tree regressions, which had been pooled for all treatments (Section 5.30, Table 8). The pooling was carried out as the poor fit of full-tree data precluded the detection of treatment effects.

Poor fit may have arisen because of: (1) relatively small sample numbers, n = 6 trees per treatment, (2) the limited diameter range of sample trees, and (3) low accuracy in total weight estimates resulting from the accumulation of errors in the many sub-component weight determinations.

A change in the proportion of biomass components in relation to treatment was expected from understanding of biological principals and consideration of the literature. The absence of differences in Tables 21 and 22 is an artifact of the use of pooled prediction equations. To examine the relationship of component weights further a separate data source was considered.

The non-destructive estimates of tree biomass of c.12 trees per treatment in 1979 were divided into tree foliar weight, tree branch wood weight and tree total branch weight (Table 23).

TABLE 23: The relationship between tree biomass components as predicted from summed weights predicted from branch regressions.

	Control	Fertilised	Thinned	Fert. + Thin.
Tree foliar weight (kg)	6.98	9.14	9.20	10.73
Tree branch wood weight (kg)	9.27	11.12	10.82	10.22
Tree total branch weight (kg)	16.28	20.20	20.01	23.28

These estimates were derived by summing the predicted component weights of individual branches. The fertilised, thinned and combined treatment reveal an increase in mean tree foliar needle weight of 31, 32 and 54% respectively two years after treatment. The full tree relationships, as analysed in Section 5.30, did not detect this treatment difference in foliar production.

As a check upon the comparability of the two types of data the ratio of branch wood weight to branch foliar weight was calculated. The ratios should approximate each other when all treatments in Table 23 are averaged. In fact the full tree ratio is 1.15 (Table 22) and the ratio from summed branch weights (Table 23) 1.13. Thus, while Tables 21 and 22 may give useful total weights, the relationships between components must be treated with some caution.

6.20 ANNUAL ESTIMATES OF INDIVIDUAL TREE CROWN BIOMASS

The non-destructive estimates of crown foliar biomass in this study were derived from the summation of individually predicted branch foliar weights. These were associated with the measured branch diameters of c.12 trees per treatment. Before analysing these estimates it is desirable to test their accuracy and precision against known weights.

6.21 Evaluation of predictive methodology

Branch foliar weights from 12 destructively harvested trees in August 1977 were summed over 5% relative height zones and divided by the number of sample trees to give a mean tree foliar weight distribution (Figure 11).

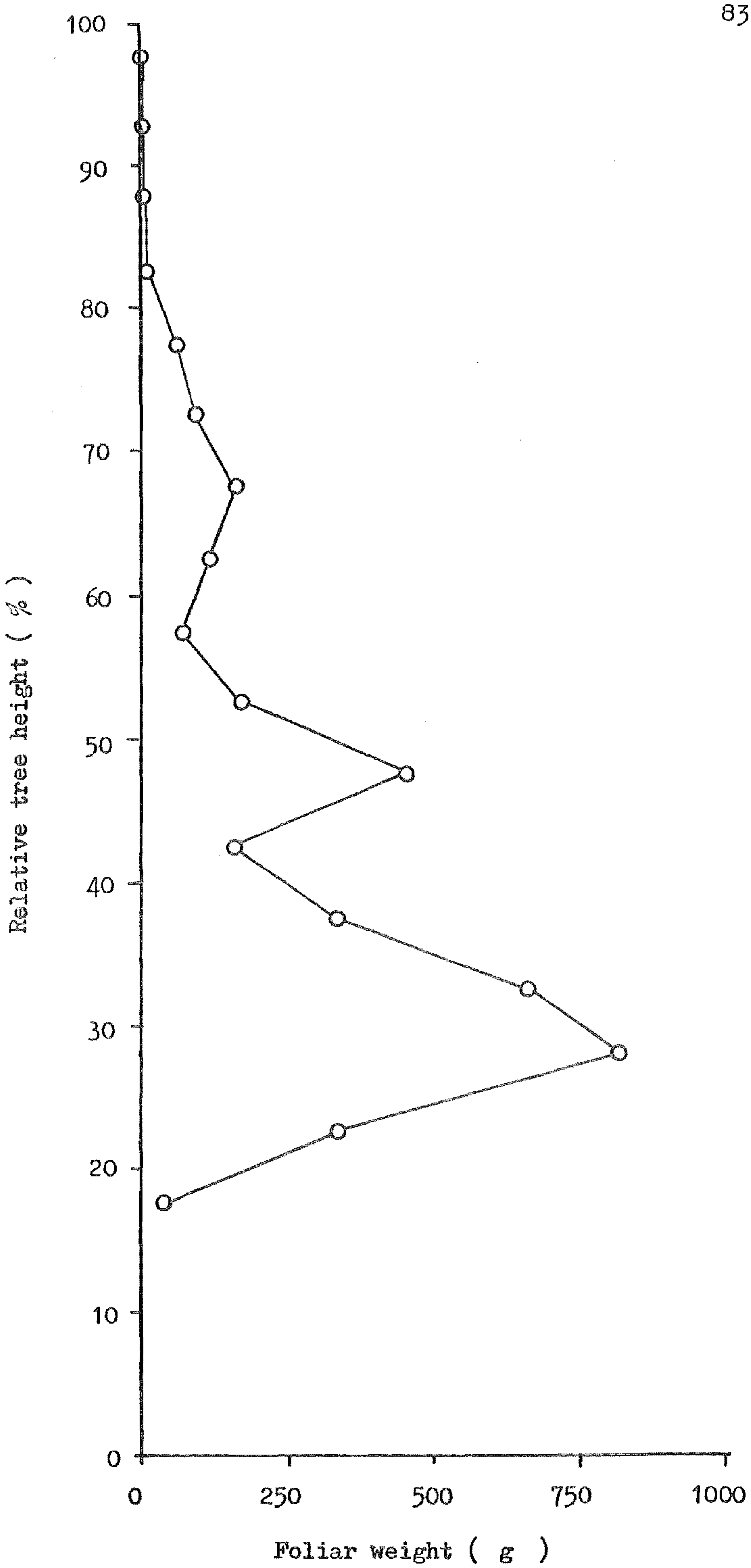


FIGURE 11. Mean tree foliar weight distribution. August 1977.

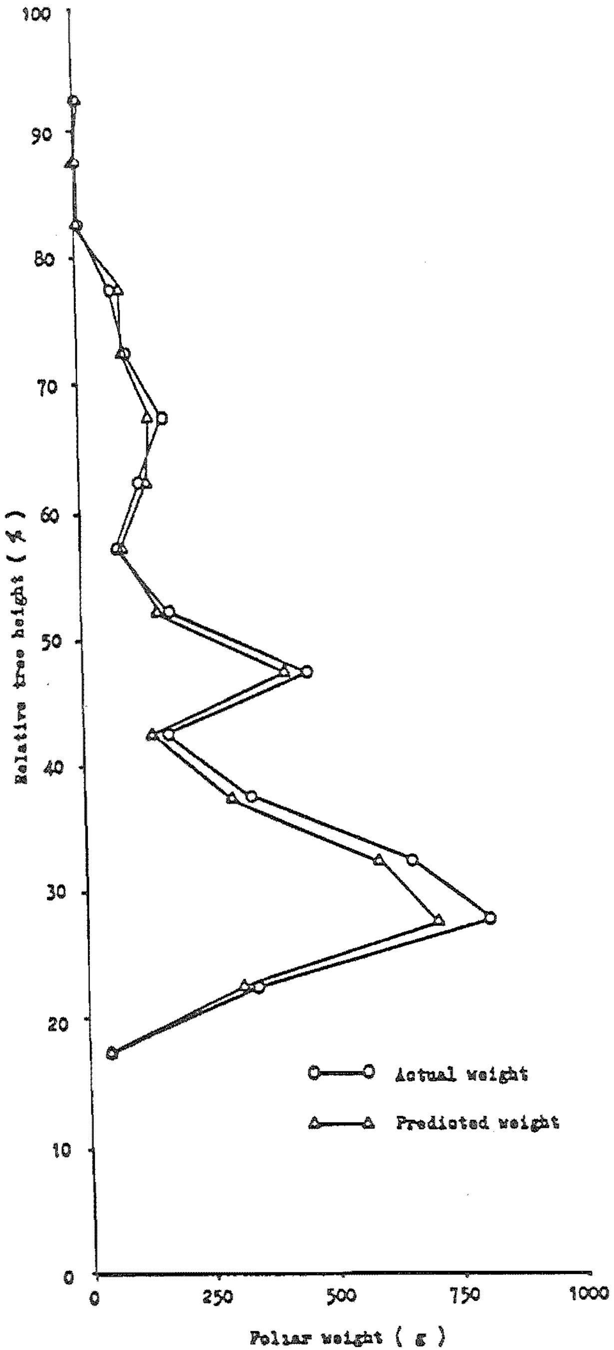
This procedure was then repeated using branch foliar weights predicted from the measured diameters and branch regressions independently calculated by crown position. The predicted weights (ln bias adjusted) are compared to known foliar weights in Figure 12(a) while the per cent bias of total tree weight is given in Figure 12(b).

The largest bias is found in the mid-lower crown where foliar weights are under-estimated by -1 to -3% total crown foliar weight. A tendency to over-estimate is seen in the upper crown and crown base, although the 1 m pruning does not allow confirmation of the latter.

Madgwick and Jackson (1974) reported similar trends in bias of 1 year old needle weights predicted from branch variables without inclusion of a relative height term. The pattern of bias resulted in an overall under-estimate. It was suggested that differential rates of development of needles and branch diameter gave rise to discrepancies in upper crown predicted and actual weights. In the lower crown an unknown biological variable, postulated as shading, influences the relationship of branch diameter (D) or D^2 x branch length to branch 1 year foliar weights.

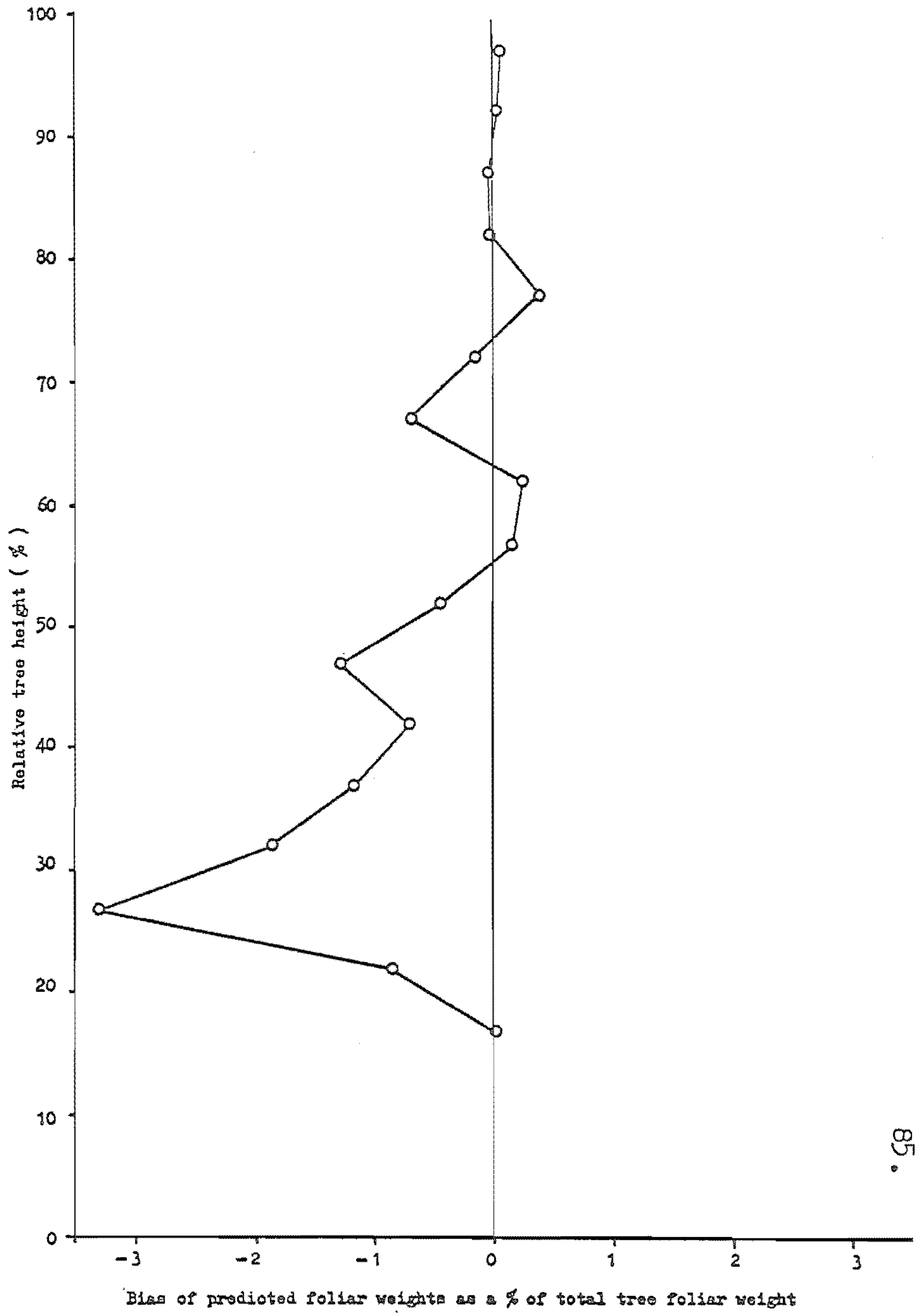
The branch diameter to branch foliar weight relationship was further considered by graphing ln mean branch foliar weight upon ln mean branch diameter, as calculated at 5% relative height zones in the tree. A free hand curve was fitted to the data and compared to a line fitted by least squares linear regression (Appendix 35).

The linear model fits the transformed data well but a comparison with the free-hand curve suggests that foliar weights



(a)

FIGURE 12: Comparison of predicted and known weights.



(b)

would be over-estimated at branch diameter extremes and under-estimated at mid range.

In this study, an attempt was made to separately define the diameter-foliar weight relationship by branch age class (annual shoots); thus reducing the range in branch diameter, and identifying a common crown position. Experience showed, however, that the diameter range at all but the most recent annual shoot were equivalent to that shown in Appendix 35. Thus, if over-estimation at branch diameter extremes is inherent in the ln-ln relationship, the stratification used in this study would not have been particularly effective in reducing this bias.

As evaluated by the pattern of predictive bias shown in Figure 12(b) some factor(s), after crown stratification, remain to effect the branch diameter to branch foliar weight relationship over position in crown. The absolute magnitude of the bias suggests its effects may not be particularly important at any specified position. In terms of total tree foliar weight the methodology underestimated by an average of 8.1%, ranging from -26% to +16%. Individual tree effects were very large in these calculations; bias did not appear well related to tree size.

6.22 Annual estimates of crown biomass

Annual estimates of individual-tree crown biomass were made in October 1977 (pre-treatment), 1978 and 1979 on a permanent sample of trees (DS1). Crown biomass was calculated from measured branch diameters (DS1) and independent branch regressions (DS3) from the preceding August biomass. Branch length, foliar weight, branch wood weight and branch total weight predictions were made from separate regressions for each time, treatment and crown position.

Results were analysed on the basis of mean annual shoot values for the trees sampled. Thus, although separate crown position regressions were employed, the analysis concerns itself with an aggregated value for each annual shoot.

Analysis in this section considers only predicted branch variables since actual branch diameter growth has been considered previously (Section 5.10). Ancova was used to reduce variation associated with differences in initial size. For analysis of mean branch length, at a given annual shoot, the pre-treatment measurement of mean branch diameter was used as a covariate. The covariate for predicted branch weight analyses was the sum of branch diameters in the pre-treatment measurement. Regressions upon the covariates were tested for linearity and influence of treatment at each annual shoot.

As no pre-treatment measurements of the current annual shoot branches were available in 1978 analysis was carried out by Anova. These tests were insensitive because the size of the error mean squares virtually precluded detection of treatment differences.

The October 1979 estimates were analysed as previously described. The covariates used for the 1977 and 1978 annual shoot analyses differed, however. Pre-treatment measurements poorly represented the 1977 annual shoots, and, as there were no indications of treatment effects at that annual shoot one year later (Table 4), these measurements were used in the October 1979 analysis.

TABLE 24: Summary of October 1978 predicted branch length and wood weight analyses. Range test at P = 0.05.

Branch variable	Annual shoot	Treatment means				CV as a % within-treatment error	Interaction
mean branch length (cm)	1973	C 151	F 158	F+T 165	T 168	91.0	ns
	1974	F 155	C 165	F+T 167	T 171	95.5	ns
	1975	T 134	C 135	F 138	F+T 139	96.4	ns
	1976	T 101	F+T 105	F 109	C 109	58.0	ns
	1977	F 51	C 59	T 60	F+T 66	46.1	ns
	1978	F+T 45	F 46	T 47	C 51	Anova	ns
total branch wood weight (g)	1973	T 1534	C 1632	F+T 1810	F 1928	86.6	ns
	1974	C 2391	F+T 2618	F 2651	T 2863	41.9	ns
	1975	C 1394	F+T 2177	T 2416	F 2476	47.8	ns
	1976	T 864	C 919	F 1045	F+T 1215	31.5	ns
	1977	C 229	T 248	F 365	F+T 373	20.1	ns
	1978	C 49	F+T 71	T 81	F 86	Anova	ns

TABLE 25: Summary of October 1978 predicted branch needle and total weight analyses. Range test at P = 0.05.

Branch variable	Annual shoot	Treatment means				CV as a % within-treatment error	Interaction
total branch needle weight (g)	1973	C 1335	T 1365	F 1671	F+T 1761	91.4	ns
	1974	C 1914	T 2126	F 2350	F+T 2468	64.3	ns
	1975	C 1456	T 1879	F+T 2178	F 2266	64.0	ns
	1976	T 887	C 879	F 1195	F+T 1370	52.1	ns
	1977	C 230	T 265	F 343	F+T 435	5.7	ns
	1978	C 75	T 115	F+T 136	F 139	Anova	ns
total branch weight (g)	1973	C 2973	T 2974	F+T 3580	F 3590	89.8	ns
	1974	C 4317	F 4971	T 5074	F+T 5108	52.2	ns
	1975	C 2881	T 4225	F+T 4335	F 4694	56.4	+
	1976	T 1739	C 1823	F 2233	F+T 2581	43.0	ns
	1977	C 462	T 512	F 712	F+T 812	12.0	ns
	1978	C 124	T 195	F+T 207	F 225	Anova	ns

Similarly, the 1978 annual shoot branch diameters showed no treatment effects after the first year and were used as covariates in the October 1979 analysis.

The analyses are summarised in Tables 26 and 27 while the information is presented graphically in Appendix 36.

Branch length treatment means evidence a slight, but significant, response to thinning after two years. Results are largely free of treatment interactions, the 1974 annual shoot alone being significant. The increase of branch length at mid and low crown levels may occur at the expense of the upper crown (Appendix 36).

Branch wood weight trends follow those previously described for branch diameter increment in that fertiliser effects are most apparent in the mid to upper crown while thinning effects are most pronounced at the crown base.

Total foliar weight alone, of the four predicted variables, departs from the pattern set by branch diameter response. Predicted foliar weights at the 1973 and 1974 level decreased over the period October 1978 to October 1979 (Tables 25 and 27). This is attributed to changes in the branch regression coefficients over time as the effect is not apparent in branch diameter response over the same period. Decreasing weights over time were also predicted in Figure 10.

Branch foliar weights, at mid crown positions, increased in the order of control, thinned, fertilised and fertilised plus thinned. After two years there was no evidence of a treatment interaction ($P \geq 0.01$) as analysed by individual annual shoot.

TABLE 26: Summary of October 1979 predicted branch length and wood weight analyses. Range test at P = 0.05.

Branch variable	Annual shoot	Treatment means				CV as a % within-treatment error	Interaction
mean branch length (cm)	1973	C 158	F 163	T 171	F+T 185	94.7	ns
	1974	F 161	C 168	T 173	F+T 178	95.3	*
	1975	C 139	F 140	T 141	F+T 151	91.2	ns
	1976	T 126	C 135	F+T 144	F 153	43.9	ns
	1977	T 89	F+T 93	C 102	F 105	43.4	ns
	1978	F+T 55	T 67	C 70	F 74	16.7	ns
total branch wood weight (g)	1973	F 1442	C 1727	T 1818	F+T 1896	89.7	ns
	1974	C 2695	F 3139	T 3359	F+T 3536	39.3	ns
	1975	C 1838	T 2973	F 3105	F+T 3246	45.7	ns
	1976	T 1515	C 1644	F 2247	F+T 2531	24.6	ns
	1977	F 772	T 886	F+T 932	C 941	67.8	ns
	1978	T 271	F+T 355	F 414	C 426	60.6	ns

TABLE 27: Summary of October 1979 predicted branch needle and total weight analyses. Range test at P = 0.05.

Branch variable	Annual shoot	Treatment means				CV as a % within-treatment error	Interaction
total branch needle weight (g)	1973	F 854	C 931	F+T 1177	T 1621	68.4	ns
	1974	C 1616	T 2451	F 2575	F+T 2966	56.0	ns
	1975	C 1588	T 2270	F 2389	F+T 2766	62.4	ns
	1976	C 1394	T 1501	F 2040	F+T 2302	39.9	ns
	1977	F 847	C 970	T 1056	F+T 1103	69.8	ns
	1978	T 298	F+T 416	F 431	C 480	62.4	*
total branch weight (g)	1973	F 2296	C 2641	F+T 3080	T 3407	85.2	ns
	1974	C 4293	F 5791	T 5812	F+T 6543	46.9	ns
	1975	C 3424	T 5232	F 5420	F+T 6021	53.4	ns
	1976	T 3038	C 3099	F 4228	F+T 4822	32.1	ns
	1977	F 1614	C 1903	T 1950	F+T 2040	69.3	ns
	1978	T 571	F+T 776	F 850	C 915	62.3	+

As noted previously (Section 5.30, 6.00) the full-tree harvest data collected in this study did not allow detection of treatment mean tree foliar differences. A second source of individual tree data is available however, by summing the non-destructive estimates of foliar weight predicted from non-destructive measurements. Furthermore, these data allow the use of Ancova techniques to reduce variation associated with initial size differences, and thus increase the sensitivity of the analysis.

Non-destructive estimates of total tree foliar weight in October 1979 were regressed upon the pre-treatment estimate of total foliar weight of the same trees (Appendix 37). Ancova indicated significant slope differences between the four treatments but no significant slope differences with the combined treatment excluded. Thus individual tree foliar weights were adjusted by a pooled slope for the control, the fertilised and the thinned treatments, and the combined treatment by its own slope. Anova of the adjusted means (Appendix 38) indicates that over the two year period the fertilised and the thinned treatments responded similarly but both were significantly different from control. The combined treatment resulted in a large, significant gain over both the fertilised and the thinned. A significant treatment interaction was measured. Response to thinning in a closed stand was approximately one half the response measured in open stand conditions.

7.00 COMPARING STEM DIAMETER INCREMENT AND CROWN BIOMASS PRODUCTION

In the original trial design dendrometer bands were to be used to monitor diameter increment at several points along the stem. Maintenance problems, caused by upper stem bark damage and excessive pitching, forced removal of the bands after 6 months. All measurements to that date were converted to over bark diameters and all subsequent measurements taken with diameter tapes.

Whyte (1974) has pointed out that the precision of over bark diameter measurements, from small samples, is generally not adequate for detecting short-term treatment differences. Over bark volume data, in this study, after adjusted by Ancova, did reveal treatment differences (Appendix 10) but the imprecision of diameter measurements made assessment of form and taper changes difficult.

Relative taper equations, calculated after one, and then two years, for the control and combined treatments showed no significant differences. However, a significant breast height diameter response was measured and no height response, therefore by definition a change in taper had occurred.

Stem diameter increments at base (0.05 m above ground), and immediately below the nodal swelling at each annual shoot indicate two basic patterns of stem diameter increment (Figure 13). The fertilised treatment pattern is essentially the same as that of the control, although the fertilised treatment emphasises upper crown increments more. The thinned treatment shows larger diameter increments in the lower stem, relative to control or to the fertilised treatment. Upper crown diameter increments were smaller than that of control relative to lower stem increments.

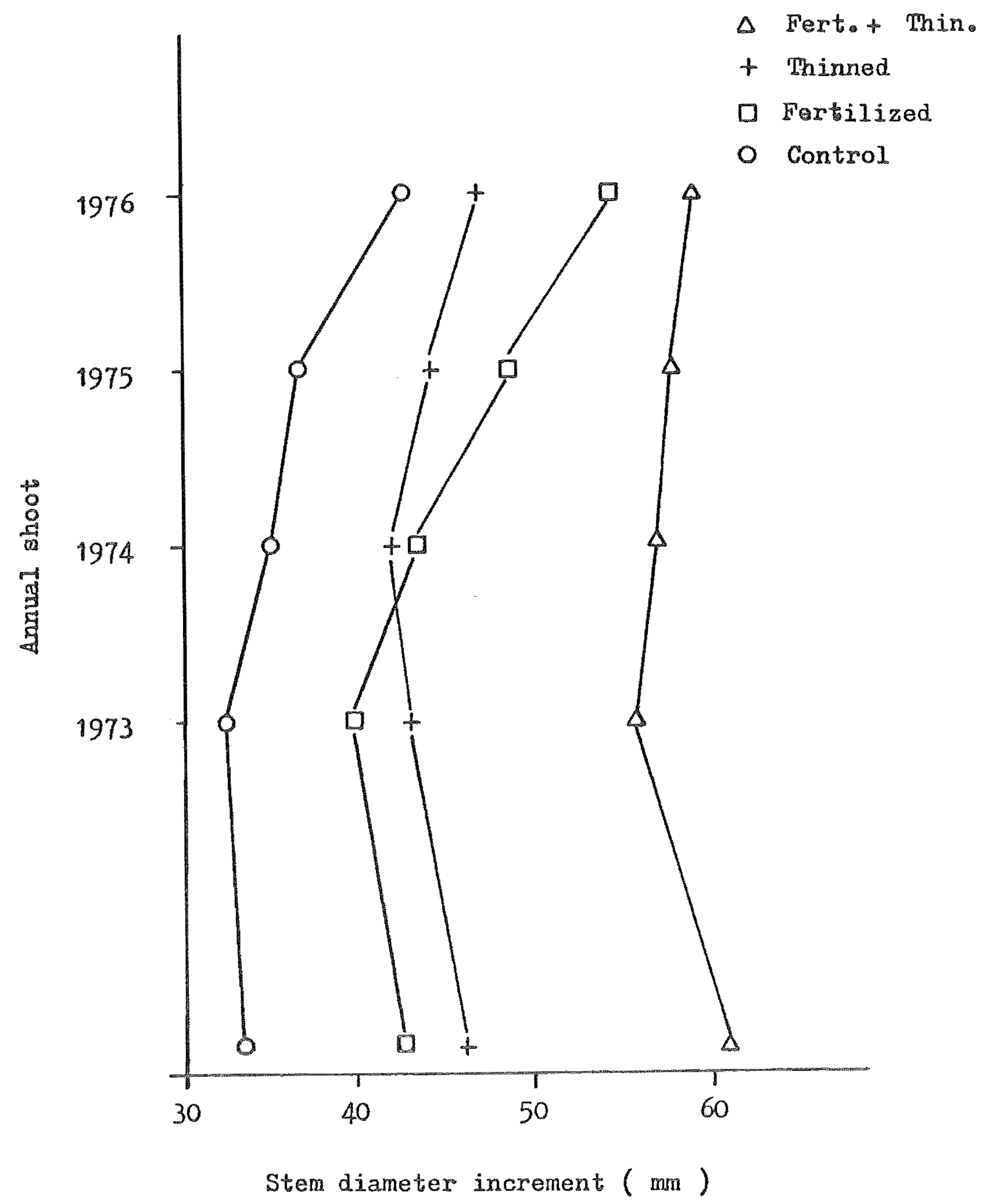


FIGURE 13. Stem diameter increment by position in crown and treatment. October 1977 to October 1979.

The combined treatment indicates a pattern intermediate to the extremes of the fertilised or thinned alone, and similar to that of control.

The stem diameter increment data show that only at the base of the crown or below is there a suggestion of treatment interaction. This was confirmed by basal area interaction, measured on a separate sample of trees (Appendix 14), at breast height (between the 1973 and 1974 measurement points).

To compare crown biomass response and stem diameter increment the response of branch diameter throughout the crown is considered first (Figure 14). After two years branch diameters of the combined treatment were significantly larger ($P \geq 0.05$) than other treatments at all but the youngest annual shoot (Table 5, Figure 14).

While it is over simplistic to consider branch diameter response in the crown as causal in the subsequent distribution of stem increment, it is more realistic to consider the relationship of branch foliar weight distribution in this regard (Labyak and Schumacher, 1954; Larson, 1963; Hall, 1965; and J.E. Barker, pers. comm., 1977).

The pattern of response to treatment found in branch foliar weight (Figure 15) is similar to that considered previously for stem diameter increment (Figure 13). Fertiliser effects are greatest in the mid to upper crown while the effects of thinning are most pronounced at low crown levels.

Further comparison of such data is complicated by: (1) lag time effects between treatment, response of crown and subsequent volume response (Albrektson et al., 1977; and Fagerström and Lohm, 1977), (2) the possible influences of different levels of foliar efficiency, and (3) the difficulty in assessing the contribution of assimilates from any given portion of the crown to diameter response. These are only three of many factors affecting the relationship between foliar weight and volume production.

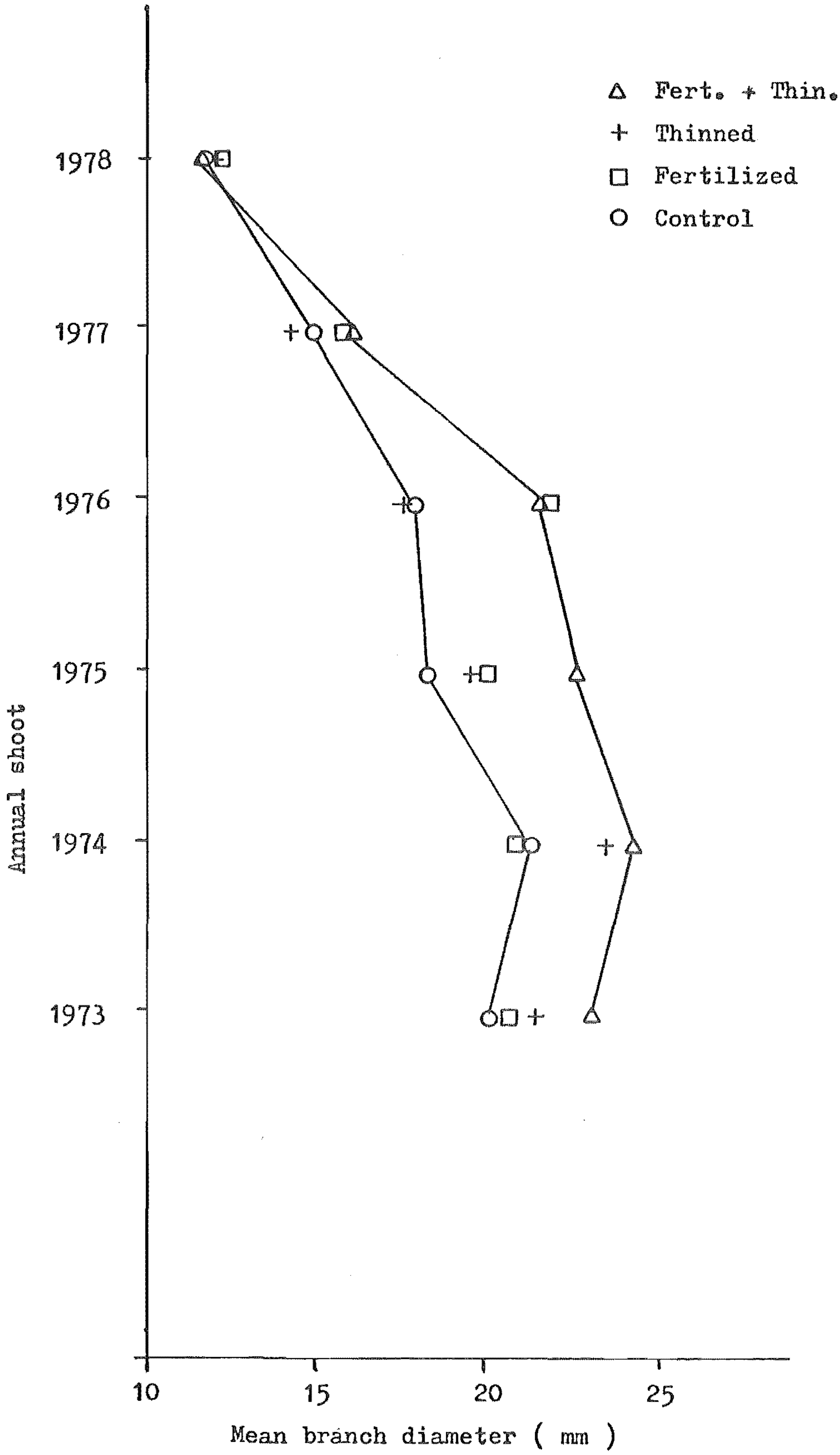


FIGURE 14: Mean branch diameter by position in crown and treatment. October 1977 to October 1979.

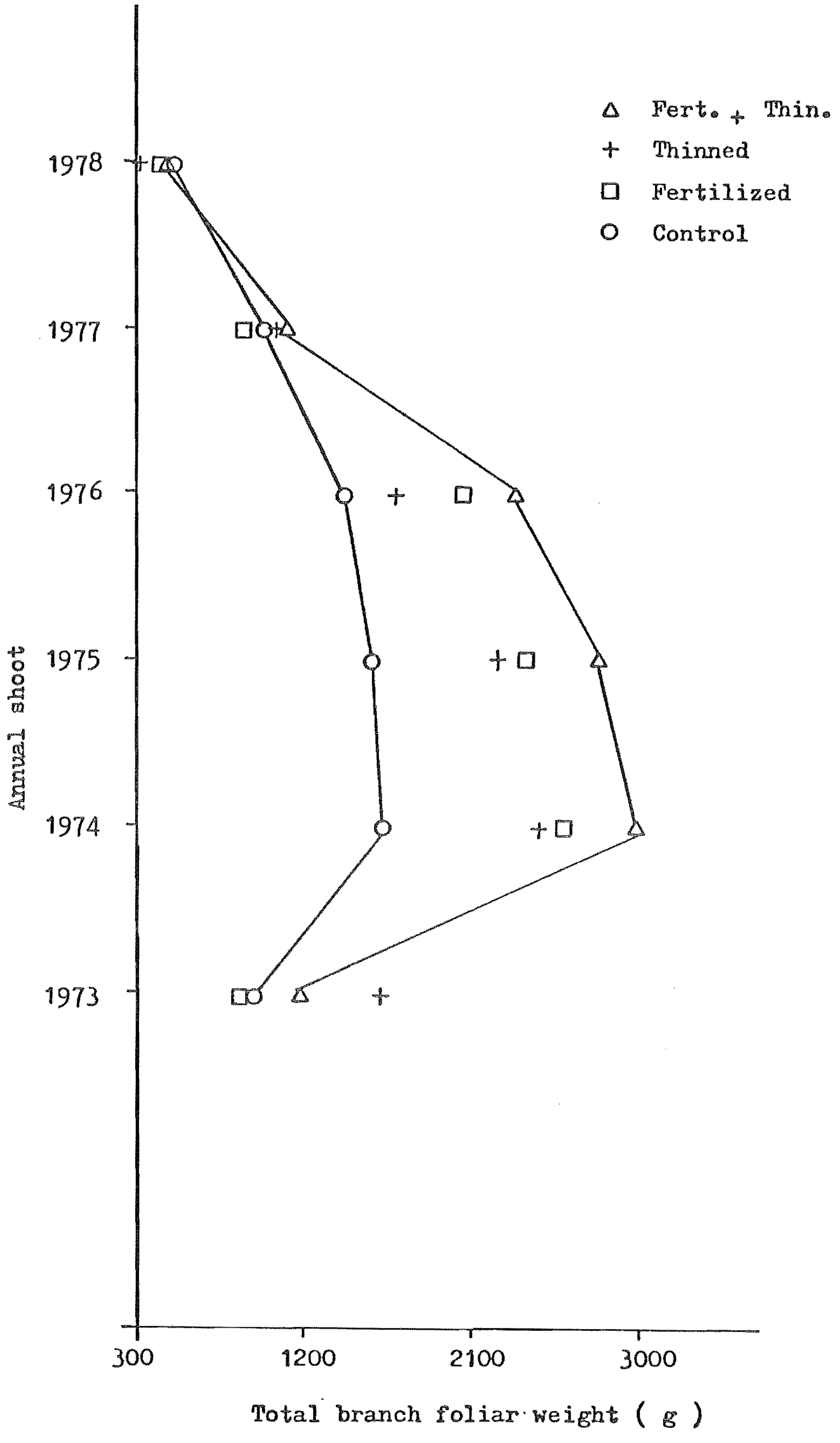


FIGURE 15: Total branch foliar weight by position in crown and treatment. October 1979.

Lag time effects were approximated by considering volume growth in year n as a function of the foliar weight at year n-1. Foliar efficiencies were also examined on the basis of this lag time relationship. Total stem volume response was considered in relationship to total tree foliar weight as the data collected in this study was insufficient to relate foliar weight responses in the crown with diameter increments at a specific point on the stem.

The volume increment of c. 12 trees per treatment, for the period October 1978 to October 1979, was regressed upon the predicted foliar weights of these same trees as estimated in October 1978, (Figure 16).

Analysis of these data indicated no significant differences in slope but highly significant differences in intercepts (Appendix 39). Fitting a pooled slope to the data shows that for a tree of 6.0 kg foliar weight the predicted foliar efficiency in volume production of thinned treatment foliage is 12% greater than that of control (Appendix 40). Fertilised foliage predicts volume responses 16% greater than control and the combined treatment 24% over control.

No evidence of a synergistic effect in increased foliar efficiency is suggested. As the foliar efficiency, or net assimilation rate (NAR) lines are parallel it suggests that a finite or bounded increase in foliar efficiency is available to all trees regardless of size. This absolute increase has no readily apparent biological explanation. If the absolute volume difference between treatment is considered on a relative growth basis it suggests that smaller trees increase more in foliar efficiency, relative to their size, than do large trees.

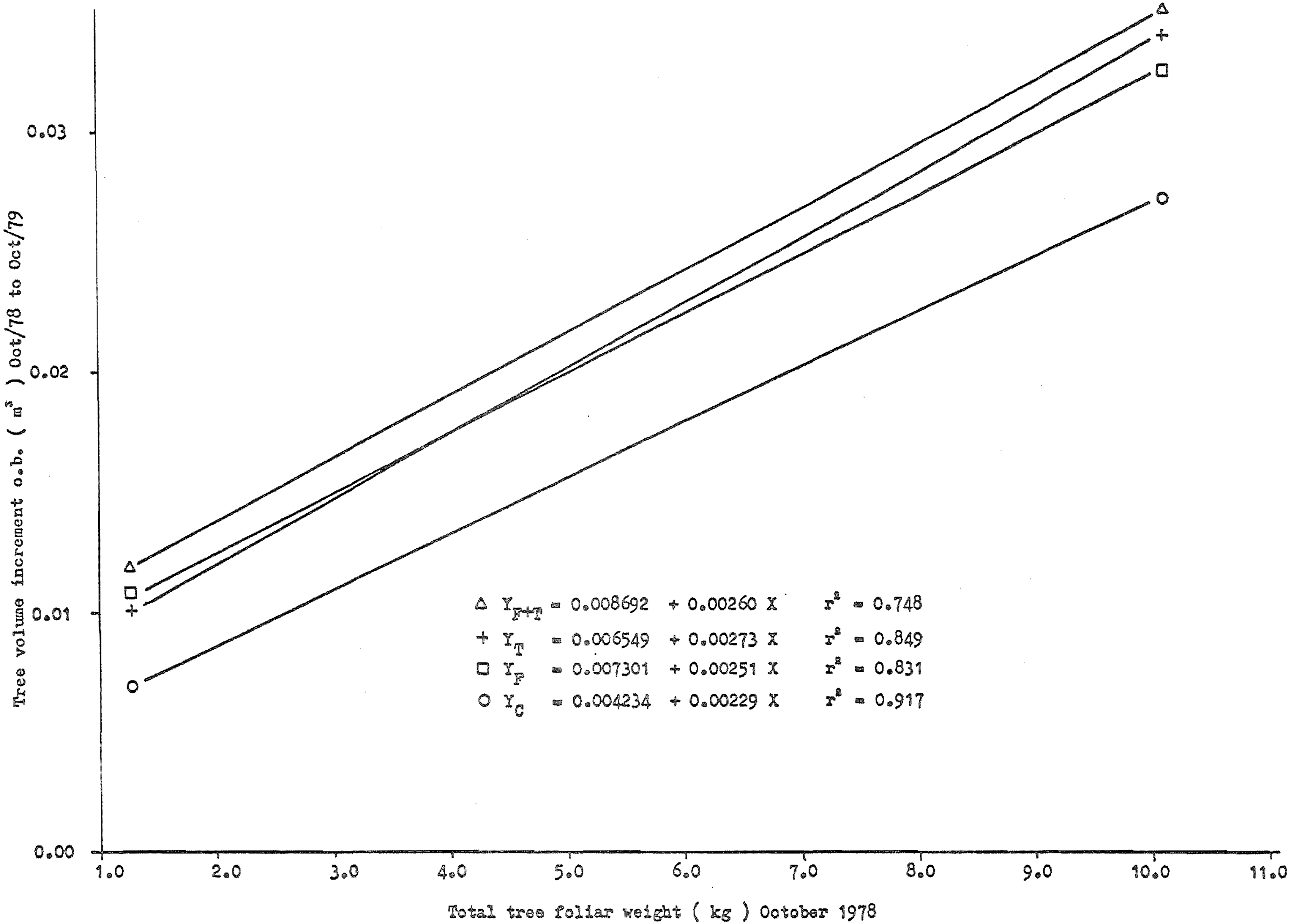


FIGURE 16: Tree volume increment (o.b.) (October 1978 to October 1979) regressed upon tree foliar weight (October 1978).

It may be speculated that small, non-competitive trees, at a given stand density, might respond at a relatively greater rate than larger dominant trees, to a treatment such as thinning which presumably increases light, and soil water availability.

With respect to fertilisation it is tempting to consider response on a per unit basis - that is, an added photosynthetic potential per unit foliar weight, or on increased assimilation area per unit of leaf area index initially present. Yet these data on foliar efficiency suggest the opposite as the largest relative gains in foliar efficiency were measured on the smallest trees.

To further examine this relationship the control and combined treatments were considered alone (Figure 17). Ancova indicated no significant slope differences but different intercepts ($P \geq 0.001$) (Appendix 41). Fitting a pooled slope to the data gives the relationships as shown in Figure 18. A treatment mean tree foliar weight was calculated for both treatments as of October 1978. After adjustment for initial tree size control trees averaged 5.63 kg foliar weight and the combined treatment trees 8.39 kg. This difference in foliar weight alone, accounts for a 38% increase in predicted tree volume increment (Figure 18). This assumes a common foliar efficiency. When differences in NAR intercepts are considered a further 25% volume increment is predicted (percentages calculated on the control mean tree volume increment).

Considering both the change in treatment mean tree foliar weight and differences in foliar efficiency a gain of 63%, combined treatment over control, in stem volume increment is predicted. The measured volume increment over that same period, after adjustment for

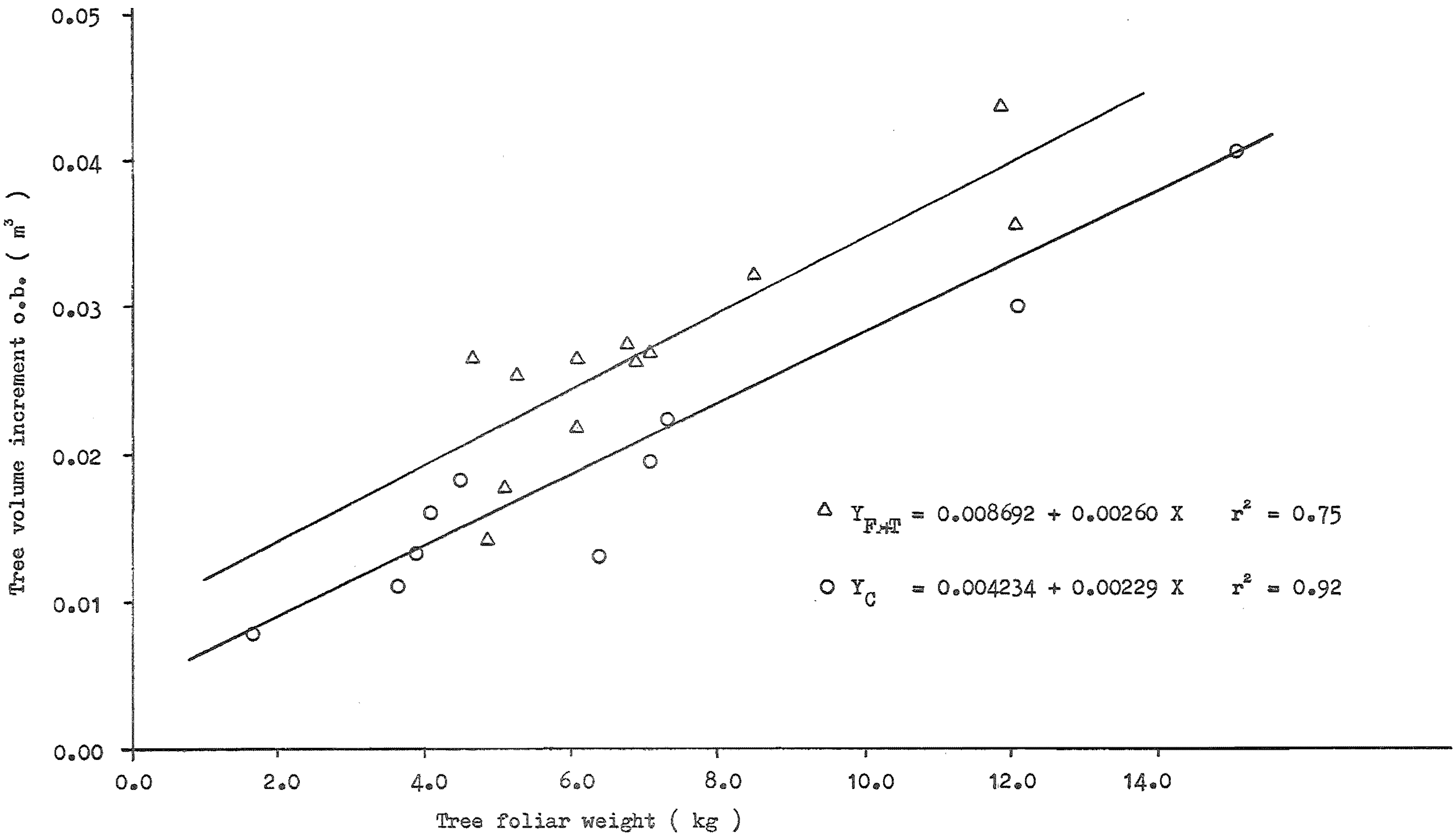


FIGURE 17: Tree volume increment (o.b.) (October 1978 to October 1979) regressed upon tree foliar weight (October 1978). Control and combined treatments.

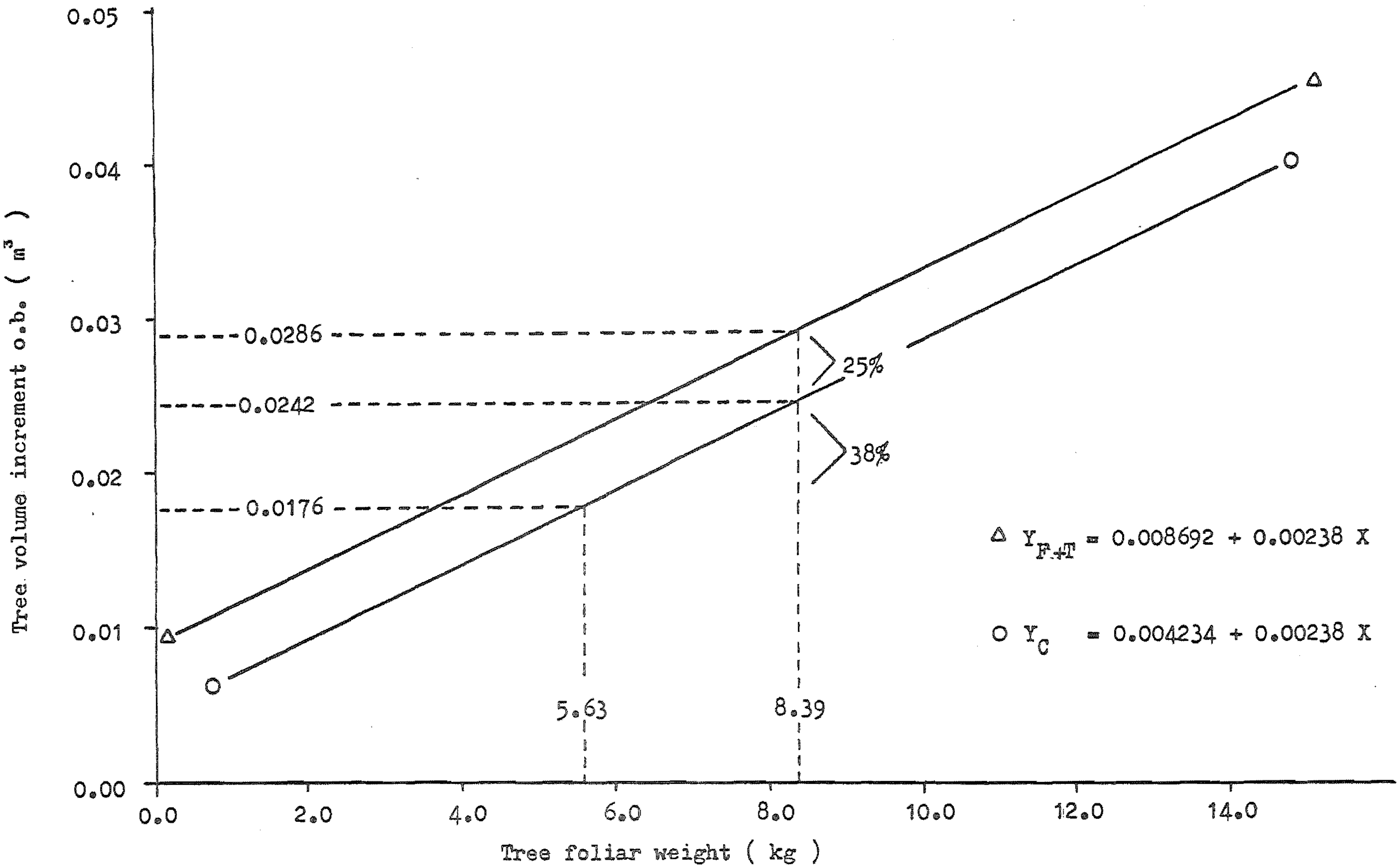


FIGURE 18: Gain in predicted volume increment associated with treatment mean tree weight and foliar efficiency.

initial size differences between the two treatments, was 0.0173 m^3 for control and 0.0299 m^3 for the combined treatment. This represents a 73% increase as opposed to the 63% increase based on predictive components.

The 10% increment not accounted for by the methodology may be associated with: (1) factor(s) not directly or indirectly measured in this study, e.g. stem needle production, (2) errors in volume or foliar weight estimates, for example Section 6.21 pointed out that foliar weights were underestimated by approximately 8%, or (3) treatment effects in the distribution of stem diameter increment thus biasing volume estimates between treatments.

Thus, it has been shown that the foliar biomass response of radiata pine to treatment, in conjunction with a measure of foliar efficiency, can predict annual volume response in the following year. This takes the explanation of the fertilisation x thinning interaction one step forward by identifying two components, which in conjunction explain 86% of the measured volume response, two years after treatment.

Tree foliar weights in 1978 (one year after treatment) showed no sign of a treatment interaction and predicted treatment differences, but no interaction in volume response in the following year. This was confirmed by measurement of volume growth in that year (Appendix 10). Tree foliar weights in 1979 however, showed a large significant treatment interaction (Appendix 38). At the time of writing it can only be anticipated that this foliar weight interaction, and measurements of foliar efficiency, will predict a stem volume interaction in the 1979-1980 growing season.

8.00 DISCUSSION

8.10 THE METHODOLOGY IN RETROSPECT

A prerequisite of the experimental objectives of this study was the development of a suitable methodology for the non-destructive estimation of crown biomass. In the absence of previously published techniques a tentative sampling framework was devised emphasising crown stratification based upon biological criteria. A retrospective evaluation of this sampling framework is warranted to identify strengths and weaknesses. Subsections which follow consider: (1) stratification of the live crown, (2) the use of individual trees as the basic unit of observation, (3) the estimation of regression coefficients, and (4) the measurements used to monitor stem profile development.

8.11 Crown stratification

The green crown of Pinus radiata was considered for sampling and predictive purposes, as a series of vertical zones, delineated by annual shoots. Analyses of branch diameters and the regressions of branch foliar weight on branch diameter, confirmed the statistical and biological significance of these annual shoot strata.

Greatest statistical gains were made by excluding one and two year old branch material from pooled branch foliar weight regressions (Table 14). While significant slope and intercept differences, between branch foliar weight on branch diameter regressions, were detected at low crown levels (four and five year old branches), results were inconsistent and interpretation of differences difficult.

Crown stratification was found to be of value in reducing the significant heterogeneity of variance associated with branch diameter measurements over the crown as a whole. After stratification by annual shoot, branch diameter variances within strata were tested and found to be homogenous.

Jacobs (1936), however, recognised that the basal cluster branches of radiata pine were of greater mean branch diameter, angle and number per cluster than were non-basal cluster branches of the same annual shoot. This relationship was observed in preliminary examination of the trees in this study and also incorporated into the sampling strategy. Basal and non-basal cluster branches were sampled and predicted as separate sub-divisions within each annual shoot to evaluate their statistical and biological importance.

Measured mean branch diameter differences, between the sub-divisions, were large in the young upper crown material but small and difficult to detect in the older branches of the lower crown.

The regressions of branch foliar weight on branch diameter differed significantly, between the two branch sub-divisions, in the upper crown but these differences in intercept decreased with branch age until, at the lower crown, no differences could be detected (Appendix 29).

The biological basis for the relationship of basal and non-basal cluster branches may be explained by the relative competitive advantage held by the basal cluster branches. These branches are usually pre-formed in the year of the previous annual shoot, and appear able to maintain this physical advantage for a two or three year period. After this time, other factor(s), perhaps mutual branch competition at the basal cluster, appear to dominate and the non-basal cluster branches show relative gains in branch diameter and branch foliar weight.

This study has shown that the differentiation of basal and non-basal cluster branches, although of biological interest, cannot be justified in a statistical sense, for branch material more than 3 years of age.

Stratification, of the green crown as a whole, was prompted by published reports of unspecified factor(s) acting along vertical gradients in the crown (Madgwick and Jackson, 1974; Ek, 1979).

The effectiveness of vertical crown stratification is interpreted, often uncritically, primarily as the result of a gradient of light availability. This interpretation, however, reflects a human observational bias and not necessarily biological fact. The crown stratification in this study, based on physiological criteria, is probably more effective, both statistically and biologically, through grouping branches of: (1) the same physiological age, (2) similar foliar morphology, and (3) the same physiological crown position with respect to allocation of assimilates, hormonal growth regulators and internal water availability.

8.12 Choice of unit of observation

In this study a relatively small sample of matched trees was measured to give repeated estimates of the response variables. Small, matched samples may be criticised on the basis of possible bias, and also imprecision, when converting responses to an area basis. On the other hand, matched samples allow precise estimates of change, and equally importantly, in association with non-destructive measurements, make Ancova procedures possible. Pre-treatment covariates commonly accounted for 45 to 90% of the within-treatment sums of squares. Thus, sensitive tests of treatment means were possible, after adjustment was made for pre-treatment size differences associated with between-sample variation.

In contrast, full-tree harvest data, from destructive measurements of random samples of trees, showed relatively large error variances. This was due in part to the particularly poor fit of full-tree data in this study but also in part to the high between-sample variability inherent in random samples of trees (Madgwick and Satoo, 1976). The numbers of randomly sampled trees selected for destructive measurements must be high to realise the same sensitivity in testing treatment means as possible by non-destructive measurements and Ancova procedures.

The biomass estimation method chosen must reflect the goals of the study. Individual tree non-destructive measurements and the Ancova procedure were found to be highly effective in: (1) estimating within-crown responses of individual trees to treatment, and (2) estimating change over time, in a small, matched sample of individual trees. However, estimates of stand biomass and stand biomass components are probably better catered for by destructive harvests of randomly sampled trees; but these objectives did not carry high priority in this study.

8.13 Regression estimates

This aspect of the methodology is concerned with the estimate of allometric regression coefficients of branch length, wood weight, needle weight, and total branch weight upon branch diameter. These regression coefficients were calculated separately at each crown position, treatment and over time. Thorough evaluation of coefficient differences was carried out for only the branch foliar weight data; however, there was no evidence of a significant departure from the foliar weight trends in the other three branch variables.

Two sources of data were evaluated: (1) data from all branches on a small, random sample of felled trees (DS3), and (2) data collected from standing trees (one branch per tree - DS4).

Branch data from felled trees were subject to problems of lack of statistical independence, but after attempts to compensate for this (p.58), produce relatively low residual mean squares from regressions (Appendix 21). Branch data from standing trees (Appendix 28) gave residual mean squares from regressions (logarithmic units) 4 to 5 times that of felled tree data. Branch numbers sampled from standing trees were roughly one-quarter of those collected from the felled tree source, but the difference in sample numbers alone did not account for the large differences in residual mean squares. The latter might be ascribed to decreased precision in the diameter measurements of detached branches. A single diameter measurement was taken, along the axis estimated at right angles to the tree main stem, on attached branches. It seemed possible to identify this same axis on detached branches but, in retrospect, its estimation may have been a source of variation in sample branch data.

Two right angle branch diameter measurements would have provided much improved estimates of diameter but were not carried out because the degree of branch crowding in the upper crown clusters physically prevented measurement in an axis paralell to the stem.

Another source of variation in branch data sampled from standing trees may have resulted from inconsistent point of cutting as the point of diameter measurement was estimated a constant distance from the branch base.

Sampling branches from standing trees has several advantages: (1) individual items of data are statistically independent, (2) the regression coefficients may be calculated from an essentially non-destructive sample, (3) field work is lessened, and (4) branch sampling allows a pre-determined weighting of (a) branch numbers in each sampling cell, and (b) the branch diameter range to be selected. The theoretical advantages the latter deserve further study as does the evaluation of branch sampling in general (c.f. Ek, 1979).

Branch variables in this study (branch length, foliar weight, wood weight and total weight) were predicted as a function of: (1) measured branch diameters, and (2) the regression of the variable of interest on branch diameter. Analyses have shown that mean branch diameter increment was significantly influenced by crown position, treatment and time (Tables 2, 3). Regression coefficient differences were small and inconsistent at all but crown position extremes (Figure 5); showed inconsistent intercept and slope differences between treatments (Table 18) and; differed primarily in intercepts over time (Table 19).

Predicted branch variables showed that branch diameter effects, were of much greater relative impact on the predicted values than were the differences in regression coefficients, estimated at given crown positions, treatments and times (Figure 10).

This implies that greater relative effort should be placed on improving the accuracy and precision of branch diameter estimates. A total enumeration of branch diameters on sample trees is advocated as a means of improving measurement precision and allowing the use of Ancova techniques. Branch regression coefficients were calculated by treatment at 3 monthly intervals in this study - analyses now suggest that annual estimates would have been sufficient.

8.14 Stem diameter measurements

Stem diameter measurements were carried out to: (1) give estimates of overbark volume of the trees for which crown biomass had been predicted, and (2) monitor the distribution of stem diameter increment patterns in response to treatment. The replacement of dendrometer bands by over-bark diameter tape measurements greatly reduced the precision of stem diameter data.

Significant volume responses, as calculated from over-bark measurements, were detected (Appendix 10) but relative taper equations of the control and combined treatment, were tested and found to be non-significant. As a significant basal area response was measured, and no height response difference detected between these treatments, a change in taper is shown, by definition, to have occurred.

Improved precision of stem diameter measurements and a re-distribution of the measurement points to estimate better the volume of the lower stem (in these small trees, a very large proportion of the total volume) would have improved the stem volume data base considerably.

8.20 BIOLOGICAL INTERPRETATION OF RESULTS

Two facts have been clearly observed in the fertilisation and thinning of radiata pine. Firstly, greatest response to fertiliser is found in combination with thinning, and secondly, fertiliser response declines with time after thinning until, after about 3 years or more, response is small and ephemeral. In seeking a biological explanation for these observed results it was noted that Tadaki (1966) postulated that the response of a "closed" stand to an artificial site improver, e.g. fertiliser, must be less than that of an "open" stand. This is because a lesser potential for increase to site equilibrium foliar biomass is present in "closed" stands.

The present study has confirmed this contention. Estimated response to fertiliser alone, as measured by adjusted mean tree foliar weight after two years, was 27% greater than control while in combination with thinning, response to fertiliser was 39% greater than thinning alone (Appendix 38). These data, based upon crop-tree measurements, show a synergistic effect or positive interaction between fertilisation and thinning and thus support Tadaki's hypothesis.

Following Tadaki's reasoning further; the observed decline in fertiliser response over time following thinning may be interpreted as the effect of increasing leaf biomass in response to thinning alone. In this study foliar biomass response over time to thinning was large and significantly greater than control, probably in an effort to re-occupy the site (Appendix 38). This thinning effect apparently reduces the potential response to fertiliser with the passage of time.

To consider further the interaction of fertilisation and thinning in this particular study it is necessary to examine treatment-site relationships.

Response to N fertilisation, in this study, was large and significant, but the site was not initially N deficient nor was there evidence of overt N deficiency symptoms in the unfertilised plots after two years. It may be speculated that nitrogen levels were present over a moderate range and were neither deficient at the unfertilised level nor, at 400 kg ha^{-1}, greatly above optimum nutrition.

The response to thinning in this trial was equivalent to, or greater than, that of fertiliser alone. A comparison of factor main effects suggests that thinning influences were greater in the first year and fertiliser main effects in the second.
It is speculated that response to thinning is primarily due to increased water availability. There are insufficient data in this trial to evaluate critically this aspect of thinning but other reviews of thinning effects on water availability indicate the influence to be potentially large (Haberland and Wilde, 1961;

de Vries and Wilde, 1962) and of direct implication in tree girth response (Butcher and Havel, 1976).

On dry sites brush control has been shown to interact with fertilisation (Powers and Jackson, 1978). As the ponderosa pine canopy in this experiment was above the competing manzanita scrub the primary effect of brush removal was given as increased water availability, rather than increased light. Brush control interacted with fertilisation on only the more infertile of the two sites tested. This was interpreted as a fertiliser x water availability interaction. Similarly, Waring (1971b) has pointed out that the response of young radiata pine to fertiliser interacts with competition by weeds or heavy stocking levels. The need to control competition for water was stressed as was the role of soil water availability in limiting the basal area increment of radiata pine (Waring, 1971a).

The measured response to thinning at Eyrewell conforms to that expected on a site where summer drought prevails and where the primary effect of thinning has probably been to increase water availability in thinned plots. The monthly increment patterns (Appendices 6, 7) show clearly the severe February-March moisture deficiency and also that the unthinned plots were most affected over this period. As the site-treatment relationship influenced branch diameter response so it also affected predictions of branch and total tree foliar weight.

Foliar weight has been used in this study as a measure of response to treatment and as a predictor variable for estimating individual tree volume response. Its relative ease of measurement justifies its use in the first instance and its apparent high predictive power its use in the second. Leaf biomass measurements should not however, be used uncritically since photosynthetic rates are more fundamentally related to leaf area, and foliar weight-area relationships vary throughout the crown. The influence of this changing relationship may be lessened by considering the crown as a whole but this results in a generalised estimate of response and the loss of valuable within-crown information.

A more basic and disturbing implication of using either foliar weight or leaf area index (LAI) in productivity trials has been pointed out by Black (1964). Agricultural treatments may interact with optimum leaf area index (LAI_{opt}) over the passage of time. Thus, truly comparable measurements of treatment response must identify the relation of current LAI to LAI_{opt}. Only when the relationship is consistent for all treatments can valid comparisons be made. The theoretical implications of this cannot be ignored, nor can the actual effect be quantified with the available data.

Foliar weight has been successfully related to periodic volume growth of pine by Lemke (1974) [F.A. 36, # 1070] and Stiell (1966). In this study the regression of annual volume increment (1978-1979) upon tree foliar weight (1978) has been shown to be linear, highly significant and influenced by treatment (Figure 16, Appendix 39). Foliar efficiency, or net assimilation rate (NAR) differences were estimated in the order of control (0%), thinned (12%), fertilised (16%) and fertilised plus thinned (24%). The biological significance of different but parallel treatment NAR's has been more fully discussed in Section 7.00, but briefly, the parallel NAR lines indicate that the increased foliar efficiency realised in response to treatment is of the same absolute magnitude over a large range of tree sizes (Figure 16). As the absolute gain is equal for all tree sizes the relative gain for small trees is much greater than that of the large trees. Thus, in response to treatment, small trees demonstrated a greater capacity to increase foliar efficiency than did the large trees.

A 15% increase in foliar efficiency of pine following N fertilisation was reported by Linder and Ingestad (1977) [from Albrektson et al. (1977) - not seen]. Change in foliar efficiency in this study (see Figure 18) was estimated to be small relative to increase in foliar biomass, which is in agreement with Watson, 1952; Brix and Ebell, 1969; Tamm, 1975; and Albrektson et al., 1977.

Increases in foliar efficiency in response to thinning have been reported by Helms (1964); Stiell (1966); and van Laar (1973) although Siemon (1973) detected no increased efficiency following thinning of radiata pine.

Foliar efficiency gains in this study over control were approximately equal for the thinned and the fertilised treatment at 12 and 16% respectively. The combination of treatments resulted in an estimated 24% increase. Thus, there is no evidence of a foliar efficiency interaction.

On the other hand, treatment mean tree foliar weights after two years, did show large significant interaction effects. The volume data for the following (third year) have not yet been measured but, based on the relationship of tree foliar weight and tree volume response a year earlier, it is anticipated that a stem volume interaction will be measured.

The stem volume response of radiata pine has been shown in this study to be a function of: (1) increased foliar biomass, and (2) increased foliar efficiency, in response to treatment. In combination these two factors predicted 86% of the measured stem volume response one year after treatment.

Increased foliar weight and foliar efficiency have been shown to be important biological steps between fertilisation and thinning and subsequent stem volume response. Further work is required on a physiological level to describe the internal allocation of tree resources to the production and distribution of foliar biomass.

9.00 SUMMARY OF RESULTS

Fertilisation and thinning of 7 year old radiata pine, both singly and in combination, brought about large, significant responses in mean tree basal area, volume increment and branch diameter growth over a two year period.

Significant, positive treatment interactions were detected in basal area increment, in tree foliar weight, and in branch diameter growth in the lower crown.

Regression of tree biomass upon tree diameter, at breast height, showed no significant treatment effects over a two year period. Conversely, independent non-destructive estimates of total tree foliar weight did provide evidence of a positive response to treatment in foliar biomass production.

No significant change in stem form could be detected from over-bark stem diameter measurements, after two years. Indirect evidence, however, suggests substantial differences in stem taper.

Regressions of branch variables on branch diameter were evaluated by position in crown, treatment and time. Inconsistent but significant effects were detected for all three factors. Regression coefficient differences were largely confined to differences in intercept.

Branch variable response (predicted from measured branch diameters and regressions of branch variable upon branch diameter) was largely determined over time by branch diameter response to treatment. Regression coefficient changes, between treatments and over time, were inconsistent and had a relatively small impact upon predicted values.

Individual tree volume increment was successfully predicted from tree foliar weight estimates and foliar efficiency. These two factors predicted a total volume increment gain (fertilised plus thinned over control) of 63%; 38% associated with increased tree foliar weight and 25% with increased foliar efficiency. The measured volume gain over the same period was 73%.

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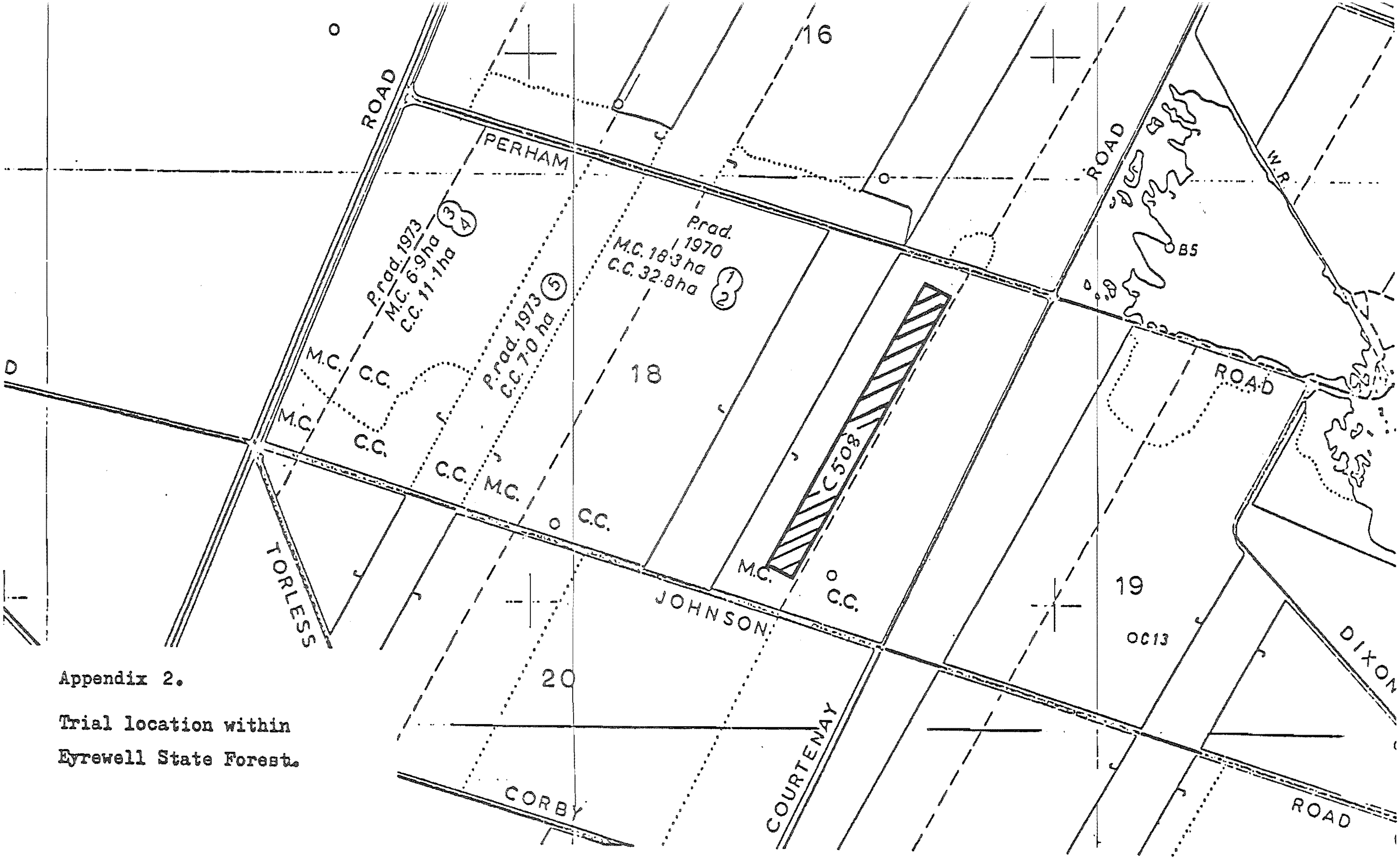
APPENDICES

Douglas fir	*Pseudotsuga menziesii* (Mirb.) Franco.
Sugi	*Cryptomeria japonica* D. Don.
Balsam fir	*Abies balsamea* (L.) Mill.
Black Spruce	*Picea mariana* (Mill.) B.S.P.
Austrian pine	*Pinus nigra* Ait.(Melv.)
Radiata pine	*Pinus radiata* D.Don.
Jack pine	*Pinus banksiana* Lamb.
Red pine	*Pinus resinosa* Ait.
Scots pine	*Pinus sylvestris* L.
Slash pine	*Pinus elliottii* Engelm.
Loblolly pine	*Pinus taeda* L.
Maritime pine	*Pinus pinaster* Ait.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Red spruce	*Picea rubens* Sarg.
Ponderosa pine	*Pinus ponderosa* Laws.

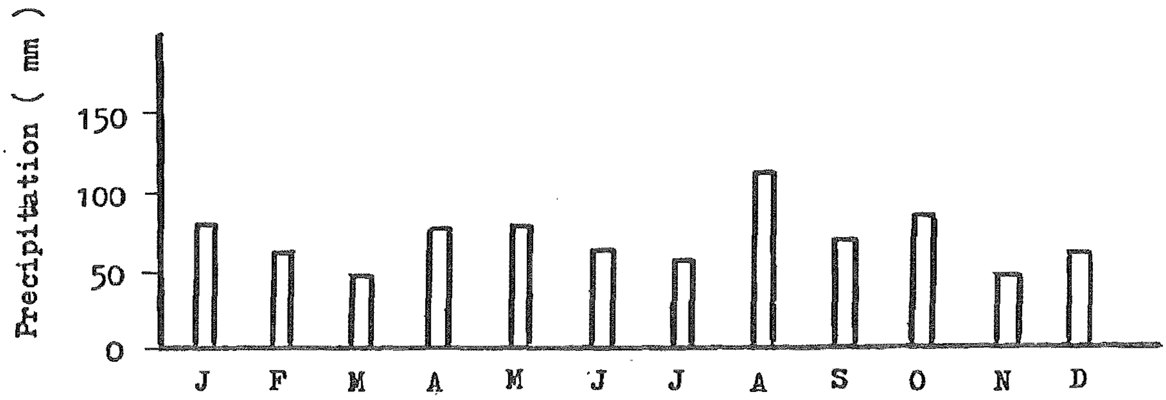
Appendix 1. Latin binomials corresponding to the common names used throughout the text.

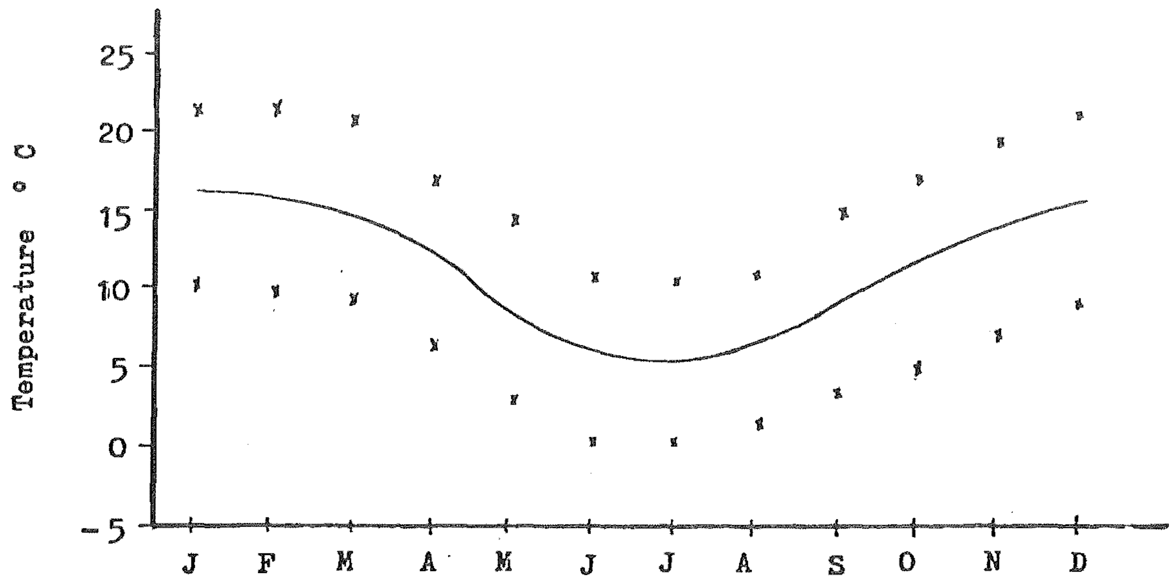


Appendix 2.

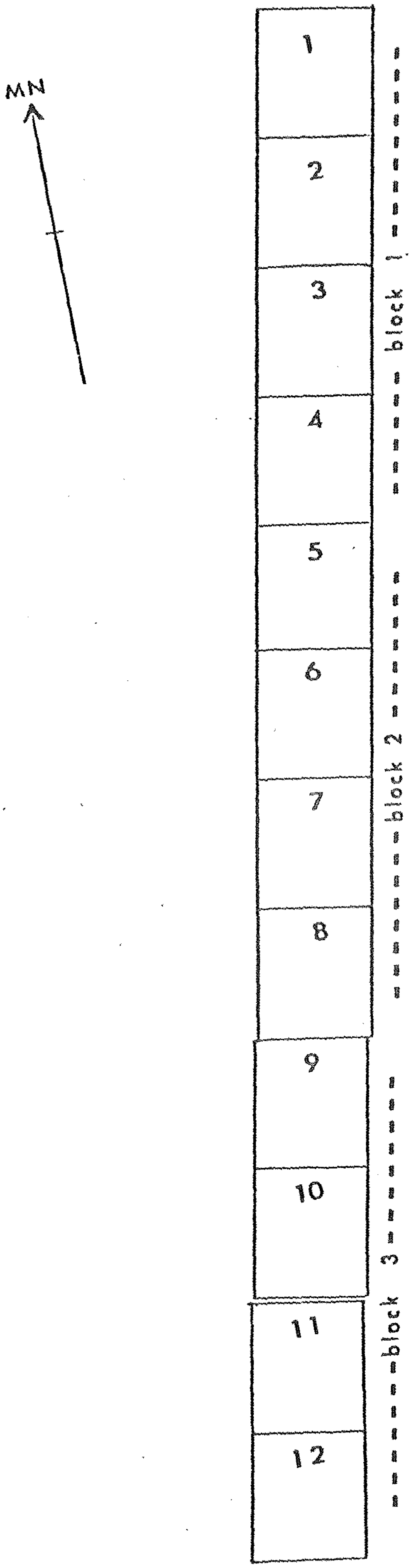
Trial location within Eyrewell State Forest.

Scale 1:10 000





Appendix 3. Average monthly daily means of temperature and precipitation for the 5 year period 1972-1976. Eyrewell Weather Station.



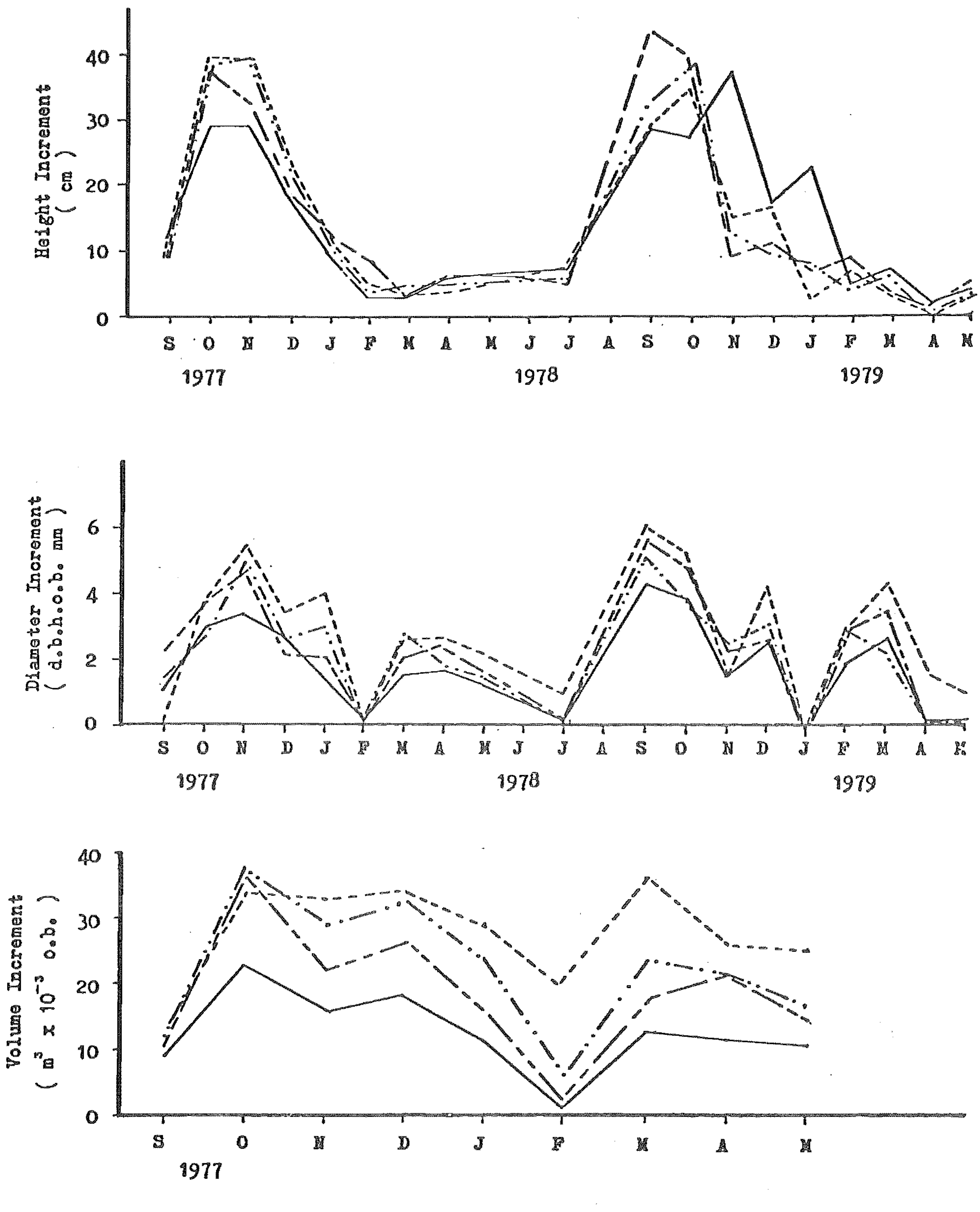
scale 1:2500

TREATMENT	PLOTS		
Control	2	6	9
Thinned (T)	3	8	11
Fertiliser (F)	4	7	12
T + F	1	5	10

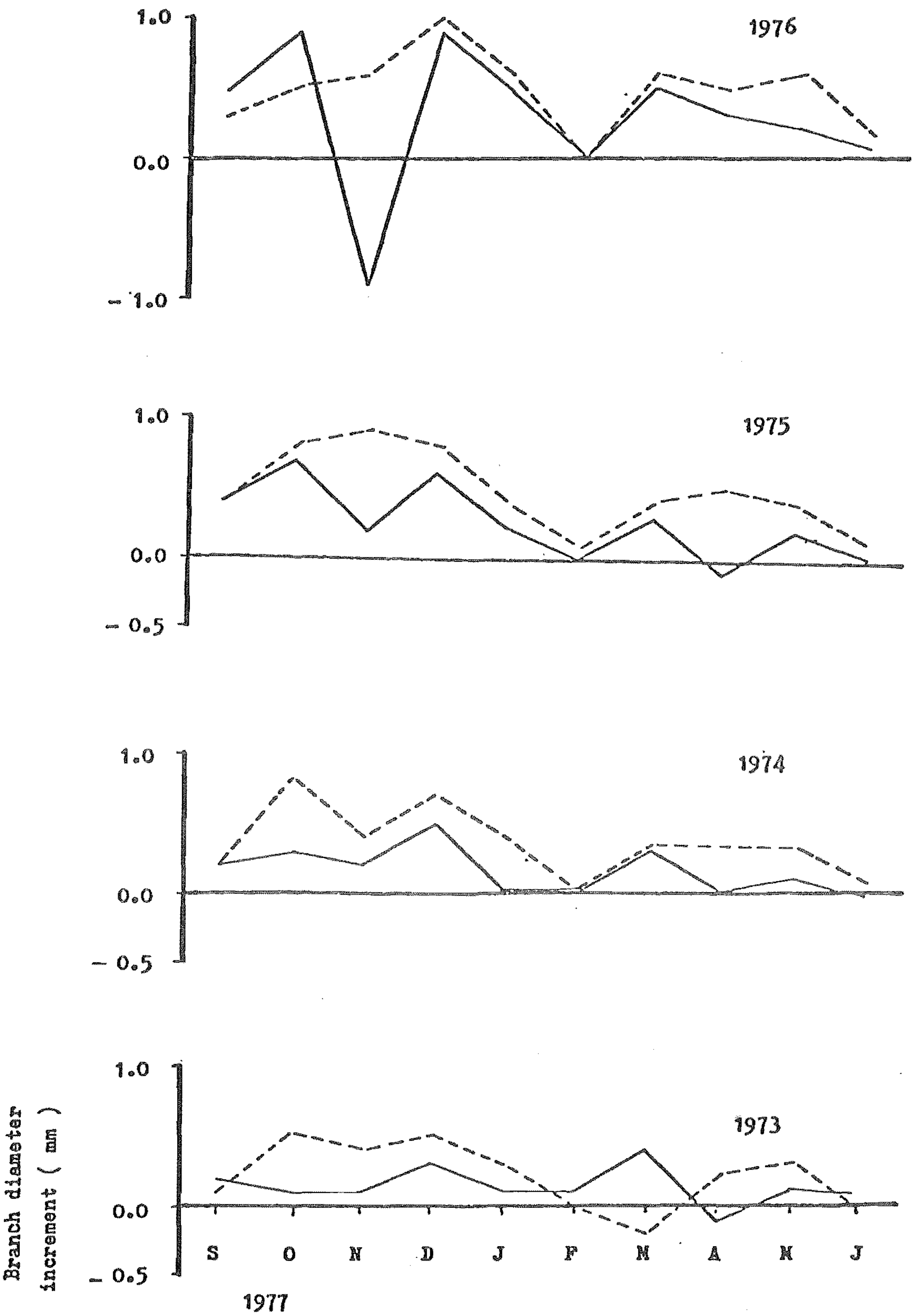
Appendix 4. Plot layout of NZFS trial C508 showing blocking and plot allocation to treatment

Plot number	Initial basal area	Unthinned Residual	Unthinned % Initial	Thinned Residual	Thinned % Initial
1	0.3825			0.1937	50.64
2	0.4207	0.2213	52.59		
3	0.3794			0.1908	50.29
4	0.3697	0.2037	55.09		
5	0.3267			0.1713	52.45
6	0.3318	0.1788	53.90		
7	0.3275	0.1688	51.54		
8	0.3285			0.1800	54.81
9	0.2976	0.1647	55.34		
10	0.3047			0.1712	56.20
11	0.3241			0.1719	53.02
12	0.2998	0.1667	55.60		

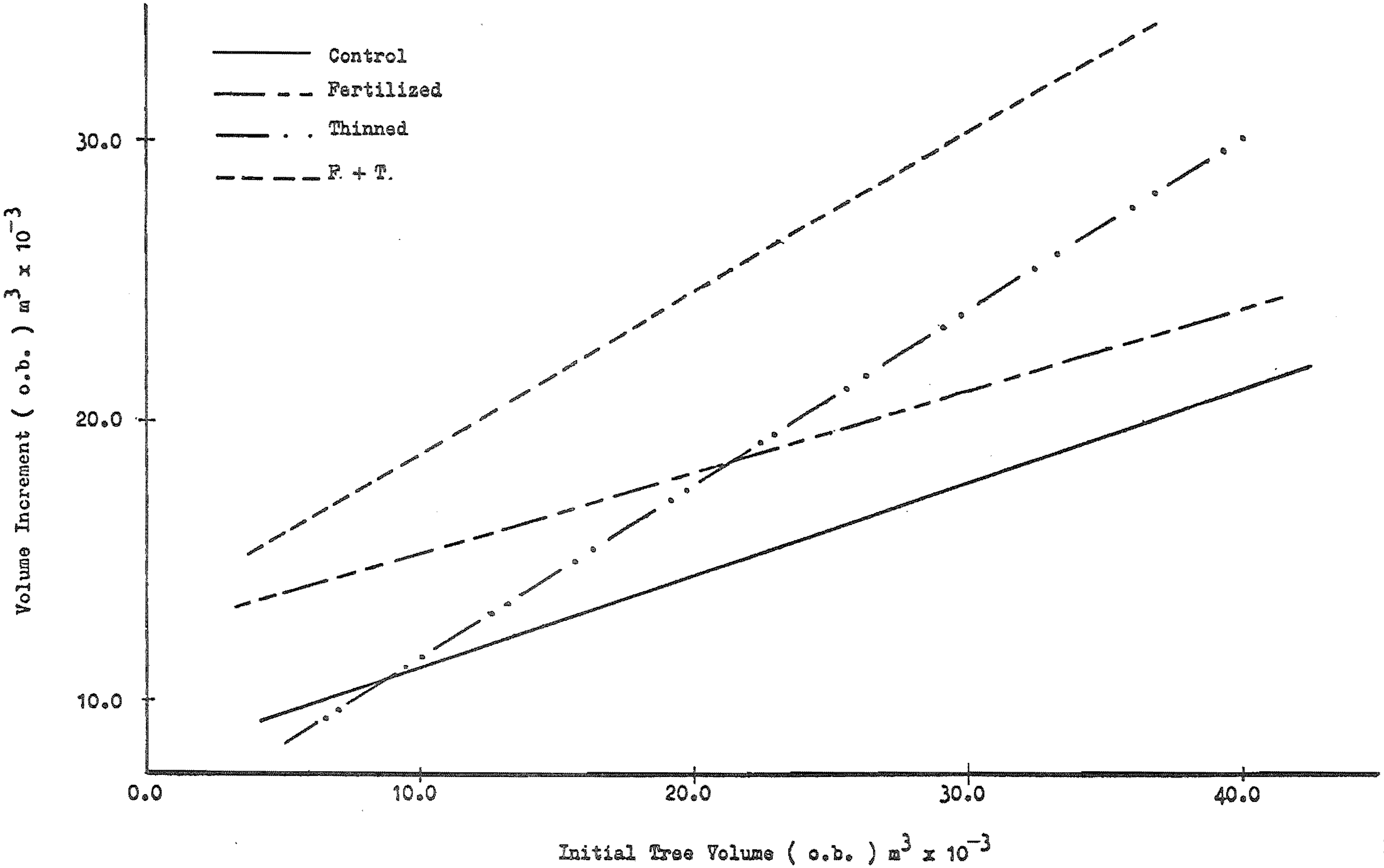
Appendix 5. Initial plot basal area and percentages designated as "thinned". (m^2)



Appendix 6. Treatment mean tree height, diameter and volume increment. Control (———), Fertilized (–·——·–) Thinned (··—··—··), Fert + Thin (– – – –).



Appendix 7. Treatment mean branch diameter increment by annual shoot for Control (————) and Fert. + Thin. (- - - - - -) treatments.



Appendix 8. First year (1977 to 1978) volume increment upon initial volume.

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	10	3319.876	1116.776	393.296	0.336	9	18.14	
Fert	10	1575.685	463.886	209.989	0.294	9	73.42	
Thin	9	429.444	272.400	194.860	0.634	8	22.07	
F + T	11	628.157	459.562	381.305	0.732	10	4.51	
						36	118.14	3.28
Pooled	40	5953.16	2312.68	1179.45	0.388	39	281.02	
		Difference between slopes				3	162.88	54.29
Between								
F + B								
		Between adjusted means						

Comparison of slopes: F = 54.29 / 3.28 = 16.55 ***
Comparison of levels: F =

Appendix 9. Ancova of treatment differences between volume increment upon initial volume regression lines.

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Within								
Cont	10	3319.880	116.780	393.297	0.3364	9	17.623	
Fert	10	1575.690	463.890	209.992	0.2944	9	73.421	
						18	91.044	5.058
Pooled	20	4895.570	1580.670	603.289	0.3229	19	92.926	4.891
		Difference between slopes				1	1.882	1.882
Between								
F + B	21	4895.590	1581.70	667.897	0.3231	20	156.873	7.844
		Between adjusted means				1	63.947	63.947

Comparison of slopes: F = 1.8820 / 5.058 = 0.372 ns
Comparison of levels: F = 63.947 / 4.891 = 13.075 **

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Within								
Thin	9	429.443	272.402	194.861	0.6343	8	22.073	
F + T	11	628.157	459.562	381.305	0.7316	10	45.088	
						18	67.161	3.731
Pooled	20	1057.600	731.964	576.166	0.6921	19	69.574	3.662
		Difference between slopes				1	2.413	2.413
Between								
F + B	21	1180.840	659.371	618.934	0.5584	20	250.748	12.537
		Between adjusted means				1	181.174	181.174

Comparison of slopes: F = 2.413 / 3.731 = 0.645 ns
Comparison of levels: F = 181.174 / 3.662 = 49.47 ***

Appendix 10. Anova of adjusted mean tree volume increment ($m^3 \times 10^{-3}$).

SOURCE	df	SS	MS	F	P
Blocks	2	3.2835	0.1413	0.03	ns
Treatments	(3)				
Fert	1	198.9188	198.9188	40.06	***
Thin	1	356.3853	356.3853	71.76	***
F x T	1	11.9701	11.9701	2.41	ns
(Co-variate)	2				
Error	36	178.7780	4.9661		
Total	41	782.7225			

Treatment Means	C	F	T	F+T
	16.07	19.31	20.76	26.11
P = 0.05				
P = 0.01				

October 1977 to October 1978

SOURCE	df	SS	MS	F	P
Blocks	2	145.3645	72.6822	6.50	***
Treatments	(3)				
Fert	1	589.1458	589.1458	52.69	***
Thin	1	310.2797	310.2797	27.75	***
F x T	1	0.3641	0.3641	0.03	ns
(Covariates)	3				
Error	35	391.3431	11.1812		
Total	40	1548.2055			

Treatment Means	C	T	F	F+T
	18.15	23.32	25.35	30.89
P = 0.05				
P = 0.01				

October 1978 to October 1979

SOURCE	df	SS	MS	F	P
Blocks	2	186.8247	93.4124	4.00	*
Treatments	(3)				
Fert	1	1680.2328	1680.2328	72.03	***
Thin	1	1394.4855	1394.4855	59.78	***
F x T	1	6.5941	6.5941	0.28	ns
(Covariates)	3				
Error	35	316.4681	23.3277		
Total	40	4386.9373			

Treatment Means	C	T	F	F+T
	33.42	44.00	45.11	57.26
P = 0.05				
P = 0.01				

October 1977 to October 1979

SOURCE	df	SS	MS	F	P
Blocks	2	326.977	163.489	17.54	**
Treatments	(3)	14.348	4.783	0.513	ns
Fert	1	12.567	12.567	1.348	ns
Thin	1	1.527	1.527	0.164	ns
F x T	1	0.224	0.224	0.024	ns
Error	6	55.930	9.322		
Total	11	397.250			

Treatment Means	F + T	F	T	C
Basal area	58.20	58.64	59.98	60.96
P = 0.05	- - - -	- - - -	- - - -	- - - -

SOURCE	df	SS	MS	F	P
Blocks	2	0.3781	0.1891	0.018	ns
Treatments	(3)	0.0267	0.0089	4.761	*
Fert	1	0.0075	0.0075	4.012	+
Thin	1	0.0192	0.0192	10.270	*
F x T	1	0.0001	0.0001	0.018	ns
Error	6	0.0112	0.0019		
Total	11	0.4161			

Treatment Means	F + T	T	F	C
Height	5.14	5.19	5.22	5.27
P = 0.05	- - - -	- - - -	- - - -	
			- - - -	- - - -
P = 0.01	- - - -	- - - -	- - - -	- - - -

Appendix 11. Pre-treatment plot mean tree basal area (cm^2) and height (m).

SOURCE	df	SS	MS	F	P
Blocks	2	0.7487	0.3743	27.479	***
Rips	1	0.0417	0.0417	3.059	+
B x R	2	0.0063	0.0032	0.232	ns
Error	18	0.2452	0.0136		
Total	23	1.0419			

Rip Means	Deep Rip	Shallow Rip
Height	5.17	5.25

SOURCE	df	SS	MS	F	P
Blocks	2	649.887	324.944	19.856	***
Rips	1	84.300	84.300	5.151	*
B x R	2	19.680	19.680	0.601	ns
Error	18	294.570	16.365		
Total	23	1048.440			

Rip Means	Deep Rip	Shallow Rip
Basal area	57.57	61.32

Appendix 12. Pre-treatment plot mean tree height (m) and basal area (cm^2) Anova.

SOURCE	df	SS	MS	F	P
Blocks	2	360.152	180.076	8.806	**
Rips	1	7.583	7.583	0.378	ns
Treatments	(3)	5822.856	1940.952	94.912	***
Fert.	1	2478.431	2478.431	121.196	***
Thin.	1	3279.513	3279.513	160.639	***
F x T	1	64.912	64.912	3.174	+
Error	17	347.648	20.450		
Total	23	6538.237			

Rip Means	Deep Rips	Shallow Rips
	81.79	82.91

Appendix 13. Anova on plot mean tree basal area increment (cm^2) from June 1977 to June 1979.

SOURCE	df	SS	MS	F	P
Blocks	2	70.816	35.408	12.245	**
Treatments	(3)	447.082	149.027	51.538	***
Fert	1	96.220	96.220	33.276	**
Thin	1	326.772	326.772	113.007	***
F x T	1	24.084	24.084	8.329	*
Error	6	17.350			
Total	11	535.248			

Treatment Means	C	F	T	F + T
	29.11	31.94	36.71	45.21
P = 0.05	------			
P = 0.01	------	------		

June 1977 to June 1978

Appendix 14. Plot mean tree basal area increment (cm^2).

SOURCE	df	SS	MS	F	P
Blocks	2	27.493	13.746	8.066	*
Treatments	(3)	1134.436	377.812	221.721	***
Fert	1	652.835	652.835	383.046	***
Thin	1	480.194	480.194	281.750	***
F x T	1	0.407	0.407	0.239	ns
Error	6	10.226	1.704		
Total	11	1171.155			

Treatment Means	C	T	F	F +T
	33.10	45.38	47.48	60.50
P = 0.05		------		
P = 0.01		------		

June 1978 to June 1979

SOURCE	df	SS	MS	F	P
Blocks	2	186.364	98.182	14.671	**
Treatments	(3)	2880.621	960.207	151.190	***
Fert	1	1250.521	1250.521	196.891	***
Thin	1	1599.444	1599.444	251.828	***
F x F	1	30.656	30.656	4.827	+
Error	6	38.108	6.351		
Total	11	3105.094			

Treatment Means	C	F	T	F+T
	62.20	79.42	82.10	105.71
P = 0.05		------		
P = 0.01		------		

June 1977 to June 1979

continued . . .

SOURCE	df	SS	MS	F	P
Blocks	2	716.167	358.084	4.560	+
Treatments	(3)	567.333	189.111	2.408	ns
Fert	1	33.333	33.333	0.424	ns
Thin	1	507.000	507.000	6.456	*
F x T	1	27.000	27.000	0.344	ns
Error	6	471.167	78.528		
Total	11	1754.667			

Treatment Means	F	C	F+T	T
	121	127	137	137
P = 0.05	----------------			

June 1977 to 1978

Appendix 14. Plot mean tree height increment (cm).

SOURCE	df	SS	MS	F	P
Blocks	2	2768.667	1384.333	5.455	*
Treatments	(3)	1179.583	393.194	1.549	ns
Fert	1	630.750	630.750	2.485	ns
Thin	1	546.750	546.750	2.154	ns
F x T	1	2.083	2.083	0.008	ns
Error	6	1522.667	253.778		
Total	11	5470.917			

Treatment Means	F+T	F	T	C
	139	152	153	167
P = 0.05	----------------			

June 1978 to June 1979

SOURCE	df	SS	MS	F	P
Blocks	2	1566.500	783.250	3.303	ns
Treatments	(3)	1237.666	412.555	1.740	ns
Fert	1	1200.000	1200.000	5.060	+
Thin	1	16.333	16.333	0.069	ns
F x T	1	21.333	21.333	0.090	ns
Error	6	1422.833	237.139		
Total	11	4227.000			

Treatment Means	F	F+T	T	C
	272	273	290	295
P = 0.05	----------------			

June 1977 to June 1979

continued . . .

SOURCE	df	SS	MS	F	P
Blocks	2	0.187	0.093	4.490	+
Treatments	(3)	0.165	0.055	2.626	ns
Fert	1	0.149	0.149	7.151	*
Thin	1	0.015	0.015	0.718	ns
F x F	1	0.002	0.002	0.095	ns
(Co-variate)	1				
Error	5	0.104	0.021		
Total	10	0.456			

Treatment Means	F+T	F	T	C
	8.11	8.16	8.39	8.49

P = 0.05

P = 0.01

Anova of adjusted plot mean tree height means. June 1979. (m)

SOURCE	df	SS	MS	F	P
Blocks	2	899.259	449.629	15.760	***
Treatments	(3)	2197.515	732.505	25.676	***
Fert	1	962.483	962.483	33.737	**
Thin	1	1158.171	1158.171	40.596	***
F x F	1	76.861	76.861	2.694	ns
Error	6	171.175	28.529		
Total	11	3267.949			

Treatment Means	C	F	T	F+T
	127.12	139.97	141.71	164.68

P = 0.05

P = 0.01

Anova of plot mean tree basal area. June 1979. (cm^2)

Appendix 14. Analysis of plot mean tree height and basal area in June 1979.

	(1) Internodal volume (i.b.) m^3 mean (range)	(2) Internodal volume (o.b.) as % of (1) mean (range)	(3) Annual shoot volume (o.b.) as % of (1) mean (range)	(4) Annual shoot volume (o.b.) as % of (2) mean (range)
August 1977				
	0.0180 (0.0045 – 0.0347)	120.05 (109.09 – 131.51)	128.82 (111.63 – 140.00)	107.40 (95.05 – 126.50)
August 1978				
Control Treatment	0.0383 (0.0155 – 0.0637)	120.89 (116.09 – 128.39)	131.96 (127.03 – 134.75)	109.17 (104.97 – 112.67)
Fertilized Treatment	0.0340 (0.0158 – 0.0491)	125.15 (119.76 – 134.06)	137.31 (128.57 – 152.59)	109.66 (104.91 – 112.50)
Thinned Treatment	0.0327 (0.0128 – 0.0503)	123.00 (116.44 – 132.84)	141.16 (123.56 – 151.99)	114.78 (106.11 – 125.43)
Fert. + Thin Treatment	0.0288 (0.0183 – 0.0459)	128.00 (122.92 – 132.79)	138.48 (128.37 – 147.47)	108.21 (100.28 – 115.74)
August 1979				
Control	0.0581 (0.0240 – 0.1063)	113.46 (110.19 – 121.10)	117.90 (114.49 – 126.97)	103.92 (101.63 – 105.63)
Fertilized Treatment	0.0556 (0.0221 – 0.0978)	114.39 (111.01 – 118.00)	120.01 (112.64 – 126.24)	107.39 (104.32 – 112.64)
Thinned Treatment	0.0586 (0.0261 – 0.0918)	110.10 (107.28 – 113.07)	115.56 (112.31 – 119.50)	104.97 (102.11 – 108.57)
Fert. + Thin. Treatment	0.0559 (0.0357 – 0.0989)	114.59 (110.90 – 117.50)	120.23 (114.21 – 130.08)	105.61 (102.43 – 110.69)

Appendix 15. Comparison of two volume estimation methods.

Biomass component (kg)	a	b	RMS	r^2	n
Ln total tree weight	-2.0145	1.08873	0.0194	0.940	12
Ln total tree branch wood weight	-4.5104	1.3069	0.0211	0.958	12
Ln total tree branch foliar weight	-3.4335	1.0822	0.0363	0.901	12
Ln total tree stem weight	-2.476	0.9998	0.0314	0.890	12

Appendix 16. Regression of dry weight biomass components upon d^2. August 1977 (pre-treatment).

Treatment	a	b	RMS	r^2	n
Cont	− 4.3554	1.2455	0.0117	0.967	6
Fert	− 3.0006	0.9788	0.0589	0.727	6
Thin	− 2.7914	0.9174	0.0118	0.951	6
F + T	− 3.5888	1.0996	0.0529	0.802	6

Ln total tree foliar weight (kg)

Treatment	a	b	RMS	r^2	n
Cont	− 3.2442	1.2309	0.0029	0.991	6
Fert	− 3.0236	1.1780	0.0264	0.896	6
Thin	− 3.2103	1.2380	0.0209	0.952	6
F + T	− 1.1586	0.7700	0.0340	0.755	6

Ln total tree stem weight (kg)

Cont	− 6.9227	1.7787	0.0066	0.991	6
Fert	− 5.4590	1.4667	0.1056	0.769	6
Thin	− 4.7843	1.3583	0.0095	0.981	6
F + T	− 5.0157	1.3730	0.0447	0.882	6

Ln total tree branch wood weight (kg)

Cont	− 3.3345	1.3634	0.0031	0.993	6
Fert	− 2.5236	1.2002	0.0393	0.857	6
Thin	− 2.1523	1.1259	0.0047	0.987	6
F + T	− 1.5688	0.9863	0.0358	0.828	6

Ln total tree weight (kg)

Appendix 17. Regression of dry weight biomass components upon d^2 . August 1978.

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	5	0.8859	1.1034	1.4212	1.24550	4	0.0469	
Fert	5	0.6548	0.6410	0.8628	0.97879	4	0.2354	
Thin	5	1.0849	0.9952	0.9601	0.91737	4	0.0471	
F+T	5	0.7088	0.7794	1.0686	1.09961	4	0.2116	
						16	0.5410	0.0338
Pooled	20	3.3344	3.5190	4.3128	1.05535	19	0.5990	0.0315
		Difference between slopes				3	0.0580	0.0193
P + B	23	3.3435	3.5401	4.3784	1.05880	22	0.6302	0.0012
		Between adjusted means				3	0.0312	0.0104

Comparison of slopes: F = 0.0193 / 0.0338 = 0.571 ns
Comparison of levels: F = 0.0104 / 0.0315 = 0.330 ns

Ancova on total tree foliar weight regressions

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	5	0.8859	1.5758	2.8290	1.77866	4	0.0262	
Fert	5	0.6548	0.9604	1.8311	1.46668	4	0.4225	
Thin	5	1.0849	1.4736	2.0394	1.35831	4	0.0378	
F+T	5	0.7088	0.9731	1.5147	1.37925	4	0.1787	
						16	0.6652	0.0416
Pooled	20	3.3344	4.9829	8.2143	1.49439	19	0.7678	0.0404
		Difference between slopes				3	0.1026	0.0342
P + B	23	3.3435	4.9681	8.2540	1.48591	22	0.8719	0.0267
		Between adjusted means				3	0.1041	0.0455

Comparison of slopes: F = 0.0342 / 0.0416 = 0.823 ns
Comparison of levels: F = 0.0455 / 0.0404 = 1.912 ns

Ancova on total tree branch wood weight regressions

Appendix 18. Analysis of treatment differences between total tree biomass component regressions upon tree d^2. August 1978.

continued . . .

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	5	0.8859	1.0905	1.3539	1.23085	4	0.0117	
Fert	5	0.6548	0.7714	1.1043	1.17797	4	0.1057	
Thin	5	1.0849	1.3430	1.7462	1.23799	4	0.0835	
F+T	5	0.7088	0.5455	0.5557	0.76967	4	0.1359	
						16	0.3368	0.0211
Pooled	20	3.3344	3.7504	4.6702	1.12476	19	0.4519	0.0238
		Difference between slopes				3	0.1151	0.0384
P + B	23	3.3435	3.7387	4.7690	1.11820	22	0.5884	0.0396
		Between adjusted means				3	0.1365	0.0347

Comparison of slopes: F = 0.0384 / 0.0211 = 1.823 ns
Comparison of levels: F = 0.0347 / 0.0238 = 0.859 ns

Ancova on total tree stem wood weight regressions

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	5	0.8859	1.2079	1.6591	1.36337	4	0.0123	
Fert	5	0.6548	0.7860	1.1004	1.20023	4	1.1571	
Thin	5	1.0849	1.2214	1.3939	1.12588	4	0.0187	
F + T	5	0.7088	0.6990	0.8326	0.98626	4	0.1431	
						16	0.3312	0.0207
Pooled	20	3.3344	3.9143	4.9860	1.17390	19	0.3910	0.0206
		Difference between slopes				3	0.0598	0.0199
P + B	23	3.3435	3.9171	5.0108	1.17158	22	0.4216	0.0222
		Between adjusted means				3	0.0306	0.0102

Comparison of slopes: F = 0.0199/0.0207 = 0.963 ns
Comparison of levels: F = 0.0102/0.0206 = 0.495 ns

Ancova on total tree total weight regressions

Appendix 18. Analysis of treatment differences between total tree biomass component regressions upon tree d^2. August 1978.

Treatment	a	b	RMS	r^2	n
Cont	– 3.5538	1.0428	0.0112	0.950	6
Fert	– 3.3040	1.0332	0.0403	0.887	6
Thin	– 5.2533	1.3998	0.0337	0.905	6
F + T	– 2.0668	0.8129	0.0264	0.805	6

Ln total tree foliar weight (kg)

Treatment	a	b	RMS	r^2	n
Cont	– 3.9227	1.3722	0.0062	0.983	6
Fert	– 2.5061	1.0875	0.0189	0.949	6
Thin	– 3.1465	1.2008	0.0169	0.949	6
F + T	– 2.4531	1.0721	0.0075	0.962	6

Ln total tree stem weight (kg)

Treatment	a	b	RMS	r^2	n
Cont	– 6.6443	1.6769	0.0015	0.997	6
Fert	– 4.3170	1.2472	0.0809	0.851	6
Thin	– 6.5268	1.6544	0.0659	0.900	6
F + T	– 4.6444	1.3295	0.0248	0.922	6

Ln total tree branch wood weight (kg)

Treatment	a	b	RMS	r^2	n
Cont	– 3.5003	1.3880	0.0015	0.996	6
Fert	– 1.9969	1.1016	0.0150	0.960	6
Thin	– 1.4896	1.4896	0.0303	0.876	6
F + T	– 1.7304	1.0536	0.0009	0.995	6

Ln total tree weight (kg)

Appendix 19. Regression of dry weight biomass components upon d^2. August 1979.

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	5	0.7728	0.8058	0.8849	1.04279	4	0.0446	
Fert	5	1.1903	1.2299	1.4320	1.03324	4	0.1613	
Thin	5	0.6576	0.9205	1.4234	1.39977	4	0.1350	
F + T	5	0.6629	0.5389	0.5438	0.81290	4	0.1058	
						16	0.4467	0.0279
Pooled	20	3.2835	3.4950	4.2842	1.06441	19	0.5641	0.0297
		Difference between slopes				3	0.1174	0.0391
P + B	23	3.3042	3.5573	4.6715		22	0.8417	0.0383
		Between adjusted means				3	0.0278	0.0925

Comparison of slopes: F = 0.0391 / 0.0279 = 1.402 ns
Comparison of levels: F = 0.0925 / 0.0297 = 3.116 +

Ancova on total tree foliar weight regressions

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	5	0.7728	1.2958	2.1791	1.67693	4	0.0361	
Fert	5	1.1903	1.4845	2.1752	1.24720	4	0.3237	
Thin	5	0.8659	1.4325	2.6335	1.65442	4	0.2635	
F + T	5	0.6629	0.8813	1.2708	1.32954	4	0.0990	
						16	0.6923	0.0433
Pooled	20	3.4918	5.0942	8.2585	1.45891	19	0.8266	0.0435
		Difference between slopes				3	0.1343	0.0448
P + B	23	3.5351	5.1551	8.5237	1.45827	22	1.0062	0.0457
		Between adjusted means				3	0.1796	0.0599

Comparison of slopes: F = 0.0448 / 0.0433 = 1.035 ns
Comparison of levels: F = 0.0599 / 0.0435 = 1.376 ns

Ancova on total tree branch wood weight regressions

Appendix 20. Analysis of treatment differences between total tree biomass component regressions upon tree d^2. August 1979.

continued . . .

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	5	0.7728	1.0604	1.4800	1.37223	4	0.0249	
Fert	5	1.1903	1.2944	1.4833	1.08748	4	0.0756	
Thin	5	0.8659	1.0397	1.3159	1.20076	4	0.0675	
F + T	5	0.6629	0.7107	0.7919	1.07212	4	0.0300	
						16	0.1950	0.0124
Pooled	20	3.4918	4.1052	5.0712	1.17567	19	0.2448	0.0129
		Difference between slopes				3	0.0468	0.0156
P + B	23	3.5351	4.1214	5.0814	1.16587	22	0.2764	0.0126
		Between adjusted means				3	0.0316	0.0105

Comparison of slopes: F = 0.0156 / 0.0124 = 1.258 ns
Comparison of levels: F = 0.0105 / 0.0129 = 0.817 ns

Ancova on total tree stem wood weight regressions

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	5	0.7728	1.0726	1.4946	1.38800	4	0.0059	
Fert	5	1.1903	1.3112	1.5043	1.10160	4	0.0598	
Thin	5	0.8659	0.8624	0.9802	0.99601	4	0.1212	
F + T	5	0.6629	0.6984	0.7393	1.05359	4	0.0034	
						16	0.1903	0.0119
Pooled	20	3.4918	3.9446	4.7183	1.12968	19	0.2622	0.0138
		Difference between slopes				3	0.0719	0.0240
P + B	23	3.5351	3.9862	4.7740		22	0.2790	0.0127
		Between adjusted means				3	0.0168	0.0056

Comparison of slopes: F = 0.0240 / 0.0119 = 2.015 ns
Comparison of levels: F = 0.0056 / 0.0138 = 0.406 ns

Ancova on total tree total weight regressions

Appendix 20. Analysis of treatment differences between total tree biomass component regressions upon tree d^2. August 1979.

Crown Position		a	b	r^2	RMS	n
1973	+	2.36880	0.88387	0.982	0.0054	10
	−	2.37462	0.87351	0.980	0.0067	10
1974	+	2.58530	0.80075	0.976	0.0056	12
	−	2.40861	0.85113	0.972	0.0087	9
1975	+	2.19067	0.92736	0.985	0.0031	10
	−	1.87267	0.96929	0.963	0.0105	9
1976	+	1.67873	1.05664	0.993	0.0028	9
	−	1.40486	1.06348	0.978	0.0134	8

Branch Length

Crown Position		a	b	r^2	RMS	n
1973	+	−1.76931	2.22675	0.992	0.0148	10
	−	−1.68068	2.23522	0.992	0.0168	10
1974	+	−1.47543	2.13524	0.996	0.0057	12
	−	−0.94881	1.99005	0.981	0.0160	9
1975	+	−0.74436	1.86072	0.990	0.0086	10
	−	−1.24636	2.00440	0.996	0.0044	9
1976	+	−1.01150	1.80087	0.995	0.0051	9
	−	−1.60797	1.80803	0.955	0.0406	8

Branch Foliar Weight

1973	+	−3.97518	2.92263	0.996	0.0116	10
	−	−3.18916	2.69283	0.991	0.0294	10
1974	+	−3.23999	2.68470	0.997	0.0087	12
	−	−2.91400	2.60231	0.996	0.0058	9
1975	+	−2.78410	2.53147	0.992	0.0135	10
	−	−3.51187	2.77231	0.995	0.0103	9
1976	+	−2.92869	2.50456	0.990	0.0217	9
	−	−3.19088	2.48926	0.991	0.0145	8

Branch Wood Weight

1973	+	−2.17297	2.57553	0.995	0.0122	10
	−	−1.77254	2.47535	0.993	0.0181	10
1974	+	−1.62461	2.39837	0.998	0.0035	12
	−	−1.19910	2.28483	0.994	0.0070	9
1975	+	−1.04412	2.18868	0.996	0.0048	10
	−	−1.64246	2.37204	0.997	0.0055	9
1976	+	−1.35154	2.17901	0.995	0.0078	9
	−	−2.04396	2.27452	0.986	0.0188	8

Branch Total Weight

Appendix 21. August 1977 (pre-treatment) branch regression relationships.

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Within								
73 +	9	3.0710	6.8403	15.3498	2.22675	8	0.1182	
73 −	9	3.3843	7.5647	17.0430	2.23522	8	0.1343	
74 +	11	3.4911	7.4544	15.9740	2.13524	10	0.0570	
74 −	8	1.4395	2.8648	5.8127	1.99005	7	0.1117	
75 +	9	1.9528	3.6336	6.8302	1.86072	8	0.0691	
75 −	8	2.0422	4.0934	8.2355	2.00440	7	0.0307	
76 +	8	2.3749	4.2769	7.7377	1.80087	7	0.0355	
76 −	7	1.5732	2.8444	5.3863	1.80803	6	0.2436	
						61	0.8010	0.01312
Pooled	69	19.3300	39.5724	82.3693	2.04721	68	1.3563	0.0199
		Difference between slopes				7	0.5562	0.0795
Between								
P + B	76	23.9273	53.3481	126.8313	2.22959	75	7.8866	0.1052
		Between adjusted means				7	6.5303	0.9329

Comparison of slopes: F = 0.0795 / 0.0132 = 6.056 ***

Appendix 22. Ancova between regressions at different crown positions. August 1977 pre-treatment data.

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
73 +	9	3.0719	6.8403	15.3498	2.22675	8	0.1182	
73 −	9	3.3843	7.5647	17.0430	2.23522	8	0.1343	
						16	0.2525	0.0158
Pooled	18	6.4562	14.4050	32.3928	2.23119	17	0.2526	0.0149
		Difference between slopes				1	0.0001	0.0001
Between								
P + B	19	7.0368	15.5078	34.4873	2.20380	18	0.3113	0.0173
		Between adjusted means				1	0.0587	0.0587

Comparison of slopes: $F = 0.0001 / 0.0158 = 0.0063$ ns

Comparison of levels: $F = 0.0587 / 0.0149 = 3.9396$ ns

1973 annual shoot

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
74 +	11	3.4911	7.4544	15.9740	2.13524	10	0.0570	
74 −	8	1.4395	2.8648	5.8127	1.99005	7	0.1117	
						17	0.1687	0.0099
Pooled	19	4.9307	10.3192	21.7867	2.09285	18	0.1903	0.0106
		Difference between slopes				1	0.0216	0.0216
Between								
P + B	20	4.9958	10.3974	21.8807	2.08122	19	0.2414	0.0127
		Between adjusted means				1	0.0511	0.0511

Comparison of slopes: $F = 0.0216 / 0.0099 = 2.177$ ns

Comparison of levels: $F = 0.0511 / 0.0106 = 4.821$ *

1974 annual shoot

Appendix 23. Ancova on basal and non-basal cluster regressions of foliar weight. August 1977 data.

continued . . .

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
75 +	9	1.9528	3.6336	6.8302	1.86072	8	0.0691	
75 −	8	2.0422	4.0934	8.2355	2.00440	7	0.0307	
						15	0.0998	0.0067
Pooled	17	3.9950	7.720	15.0657	1.93417	16	0.1204	0.0075
		Difference between slopes				1	0.0206	0.0206
Between								
P + B	18	4.2092	8.2718	16.4506	1.96514	17	0.1958	0.0115
		Between adjusted means				1	0.0754	0.0754

Comparison of slopes: F = 0.0206 / 0.0067 = 3.096 +

Comparison of levels: F = 0.0754 / 0.0075 = 10.053 **

1975 annual shoot

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
76 +	8	2.3749	4.2769	7.7377	1.80087	7	0.0355	
76 −	7	1.5732	2.8444	5.3863	1.80803	6	0.2436	
						13	0.2791	0.0215
Pooled	15	3.9481	7.1213	13.1240	1.80372	14	0.2792	0.0199
		Difference between slopes				1	0.0001	0.0001
Between								
P + B	16	4.0473	7.6757	16.2225	1.89649	15	1.6656	0.1110
		Between adjusted means				1	1.3864	1.3864

Comparison of slopes: F = 0.0001 / 0.0215 = 0.005 ns

Comparison of levels: F = 1.3864 / 0.0199 = 69.668 ***

1976 annual shoot

Appendix 23. Ancova on basal and non-basal cluster regressions of foliar weight. August 1977 data.

	df	Σx^2	Σxy	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Within								
1973	19	7.0368	15.5078	34.4873	2.2038	18	0.3113	
1974	20	4.9958	10.3974	21.8807	2.08122	19	0.2414	
1975	18	4.2092	8.2716	16.4506	1.96514	17	0.1958	
1976	16	4.0473	7.6757	16.2225	1.89649	15	1.6656	
						69	2.4141	0.0350
Pooled	73	20.2891	41.8524	89.0410	2.0268	72	2.7077	0.0376
			Difference between slopes			3	0.2936	0.0979
Between								
P + B								
			Between adjusted means					

Comparison of slopes: F = 0.0979 / 0.0350 = 2.797 *

Comparison of levels: F =

Appendix 24. Ancova between 4 annual shoots (+ and - pooled) present at time of sampling. August 1977.

Crown position		a	b	r^2	RMS	n
1973	+	2.61710	0.81512	0.970	0.0058	9
	−	1.93708	1.01149	0.990	0.0041	10
1974	+	1.90903	1.03829	0.975	0.0088	10
	−	1.64032	1.17071	0.980	0.0103	9
1975	+	1.94956	1.02754	0.950	0.0199	12
	−	1.41380	1.24057	0.997	0.0015	10
1976	+	1.35755	1.21416	0.955	0.0209	11
	−	1.12710	1.24740	0.982	0.0140	9
1977	+	1.47495	1.10500	0.993	0.0018	9
	−	0.84315	1.27001	0.989	0.0082	7

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−2.99951	2.54454	0.977	0.0417	9
	−	−2.40153	2.39121	0.993	0.0171	10
1974	+	−1.71928	2.15319	0.948	0.0820	10
	−	−1.44810	2.13128	0.990	0.0176	9
1975	+	−1.42666	2.12542	0.992	0.0139	12
	−	−1.25105	2.04885	0.993	0.0096	10
1976	+	−1.83758	2.23854	0.976	0.0381	11
	−	−2.09394	2.27069	0.996	0.0097	9
1977	+	−2.16928	2.22949	0.950	0.0591	9
	−	−2.64441	2.24395	0.984	0.0367	7

Branch Foliar Weight

1973	+	−3.49656	2.76379	0.996	0.0087	9
	−	−3.67569	2.81119	0.999	0.0038	10
1974	+	−3.66793	2.79874	0.984	0.0419	10
	−	−3.64923	2.84209	0.994	0.0192	9
1975	+	−3.75919	2.87741	0.996	0.0113	12
	−	−3.69589	2.88680	0.996	0.0107	10
1976	+	−3.59380	2.79140	0.993	0.0169	11
	−	−3.53883	2.71599	0.997	0.0102	9
1977	+	−3.93597	2.82584	0.996	0.0080	9
	−	−3.09126	2.42692	0.990	0.0269	7

Branch Wood Weight

1973	+	−2.68467	2.69558	0.988	0.0237	9
	−	−2.46030	2.63809	0.997	0.0080	10
1974	+	−2.07207	2.50110	0.972	0.0582	10
	−	−1.82968	2.46088	0.994	0.0127	9
1975	+	−1.81987	2.47715	0.996	0.0100	12
	−	−1.74834	2.46029	0.998	0.0038	10
1976	+	−2.07779	2.53653	0.991	0.0175	11
	−	−2.26259	2.54061	0.998	0.0076	9
1977	+	−2.39663	2.53968	0.988	0.0175	9
	−	−2.57398	2.47099	0.990	0.0279	7

Branch Total Weight

Appendix 25. August 1978 branch regression relationships. Control treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.32980	0.91197	0.974	0.0092	8
	−	2.13853	0.97245	0.997	0.0018	7
1974	+	2.04691	0.99159	0.973	0.0127	9
	−	1.99835	1.01394	0.989	0.0049	11
1975	+	1.90841	1.03725	0.986	0.0062	12
	−	1.41798	1.18589	0.982	0.0088	12
1976	+	1.54423	1.12386	0.971	0.0102	11
	−	0.93372	1.31868	0.991	0.0047	7
1977	+	1.47323	1.05593	0.946	0.0133	8
	−	0.01634	1.65263	0.996	0.0014	8

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−1.87616	2.27086	0.991	0.0191	8
	−	−1.39458	2.14742	0.993	0.0180	7
1974	+	−1.12212	2.01135	0.997	0.0058	9
	−	−1.41261	2.14000	0.994	0.0128	11
1975	+	−1.08553	2.03369	0.996	0.0073	12
	−	−1.25605	2.06233	0.988	0.0166	12
1976	+	−0.93761	1.90666	0.978	0.0228	11
	−	−1.24206	1.96766	0.992	0.0090	7
1977	+	−0.43306	1.47261	0.909	0.0452	8
	−	−2.87989	2.40068	0.986	0.0101	8

Branch Foliar Weight

1973	+	−3.44017	2.78424	0.998	0.0081	8
	−	−3.50197	2.78168	0.995	0.0214	7
1974	+	−3.21270	2.65698	0.999	0.0044	9
	−	−3.82364	2.88970	0.987	0.0476	11
1975	+	−3.68397	2.84307	0.999	0.0031	12
	−	−3.81680	2.87089	0.994	0.0172	12
1976	+	−3.27657	2.63758	0.987	0.0259	11
	−	−3.93642	2.86138	0.994	0.0143	7
1977	+	−3.38366	2.52609	0.967	0.0459	8
	−	−4.05658	2.81783	0.983	0.0163	8

Branch Wood Weight

1973	+	−2.02602	2.54745	0.995	0.0142	8
	−	−1.63796	2.42794	0.995	0.0164	7
1974	+	−1.39173	2.30871	0.998	0.0051	9
	−	−1.82595	2.48734	0.992	0.0212	11
1975	+	−1.57368	2.40610	0.999	0.0034	12
	−	−1.72965	2.43322	0.996	0.0084	12
1976	+	−1.37062	2.26326	0.993	0.0103	11
	−	−1.75479	2.36621	0.995	0.0073	7
1977	+	−1.17028	1.98386	0.962	0.0327	8
	−	−3.19147	2.76972	0.988	0.0115	8

Branch Total Weight

Appendix 25. August 1978 branch regression relationships. Fertilized treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.08930	0.96012	0.962	0.0123	11
	−	1.76669	1.11028	0.985	0.0091	4
1974	+	2.08486	0.98009	0.958	0.0167	15
	−	1.53900	1.18658	0.991	0.0042	10
1975	+	2.01874	0.98723	0.933	0.0165	11
	−	1.49787	1.16721	0.982	0.0085	11
1976	+	2.29290	0.85704	0.927	0.0198	9
	−	1.05768	1.28821	0.975	0.0091	11
1977	+	1.41794	1.09813	0.978	0.0046	7
	−	0.82201	1.27815	0.976	0.0136	6

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−2.65688	2.41962	0.974	0.0542	11
	−	−1.83495	2.23698	1.000	0.0012	4
1974	+	−1.35022	2.02164	0.983	0.0281	15
	−	−1.67528	2.20316	0.992	0.0115	10
1975	+	−1.79715	2.20148	0.994	0.0071	11
	−	−1.38373	2.11480	0.991	0.0143	11
1976	+	−0.69882	1.77260	0.959	0.0464	9
	−	−2.38681	2.39728	0.969	0.0386	11
1977	+	−1.35283	1.82963	0.973	0.0163	7
	−	−1.24660	1.63786	0.923	0.0878	6

Branch Foliar Weight

1973	+	−3.28504	2.70832	0.991	0.0235	11
	−	−3.38292	2.69495	0.994	0.0213	4
1974	+	−3.41422	2.74165	0.997	0.0082	15
	−	−3.73989	2.87407	0.996	0.0100	10
1975	+	−4.14041	2.97663	0.999	0.0029	11
	−	−3.71533	2.87838	0.993	0.0215	11
1976	+	−2.45544	2.33668	0.960	0.0772	9
	−	−4.12195	2.92905	0.977	0.0433	11
1977	+	−3.87123	2.73405	0.995	0.0062	7
	−	−3.06467	2.42038	0.992	0.0192	6

Branch Wood Weight

1973	+	−2.43716	2.61429	0.986	0.0328	11
	−	−2.00724	2.50364	1.000	0.0011	4
1974	+	−1.83848	2.43386	0.992	0.0180	15
	−	−2.01972	2.54191	0.996	0.0084	10
1975	+	−2.25469	2.58372	0.997	0.0045	11
	−	−1.80125	2.48019	0.993	0.0139	11
1976	+	−0.86168	2.04646	0.961	0.0582	9
	−	−2.65707	2.70130	0.982	0.0286	11
1977	+	−1.97835	2.30256	0.994	0.0057	7
	−	−1.76749	2.14336	0.977	0.0413	6

Branch Total Weight

Appendix 25. August 1978 branch regression relationships. Thinned treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	3.48119	0.50820	0.886	0.0057	6
	−	2.04825	0.98104	0.963	0.0127	8
1974	+	1.85277	1.02924	0.984	0.0077	13
	−	1.61584	1.15868	0.994	0.0032	5
1975	+	1.84392	1.02544	0.978	0.0079	13
	−	1.68620	1.06174	0.961	0.0163	11
1976	+	1.55311	1.10971	0.999	0.0001	10
	−	0.83507	1.32970	0.960	0.0278	8
1977	+	1.45549	1.05840	0.915	0.0178	8
	−	0.95038	1.19647	0.854	0.0372	7

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−1.01559	2.05872	0.993	0.0053	6
	−	−1.03006	1.97258	0.992	0.0115	8
1974	+	−1.68527	2.17683	0.994	0.0139	13
	−	−1.74377	2.25693	0.999	0.0021	5
1975	+	−1.85296	2.21634	0.986	0.0237	13
	−	−1.50970	2.14143	0.973	0.0457	11
1976	+	−1.72807	2.14917	0.984	0.0082	10
	−	−1.42230	1.96351	0.979	0.0304	8
1977	+	−0.02412	1.35468	0.895	0.0367	8
	−	−1.19744	1.55572	0.074	0.0531	7

Branch Foliar Weight

		a	b	r^2	RMS	n
1973	+	−2.73277	2.53788	0.995	0.0051	6
	−	−3.04364	2.59448	0.996	0.0090	8
1974	+	−3.53173	2.74869	0.994	0.0216	13
	−	−3.88141	2.91145	0.998	0.0079	5
1975	+	−3.91118	2.84281	0.993	0.0197	13
	−	−3.46164	2.71545	0.987	0.0356	11
1976	+	−4.30705	2.96847	0.994	0.0056	10
	−	−3.94080	2.80194	0.961	0.1191	8
1977	+	−2.79468	2.30257	0.940	0.0574	8
	−	−2.86815	2.24383	0.870	0.1140	7

Branch Wood Weight

		a	b	r^2	RMS	n
1973	+	−1.12018	2.28089	0.995	0.0041	6
	−	−1.28136	2.26387	0.995	0.0094	8
1974	+	−1.94594	2.47345	0.995	0.0140	13
	−	−2.02894	2.55557	0.999	0.0019	5
1975	+	−2.15709	2.52313	0.991	0.0195	13
	−	−1.77014	2.42583	0.984	0.0339	11
1976	+	−2.20406	2.51920	0.995	0.0037	10
	−	−1.93389	2.36575	0.975	0.0541	8
1977	+	−0.58296	1.77932	0.940	0.0348	8
	−	−1.57881	1.98087	0.872	0.0873	7

Branch Total Weight

Appendix 25. August 1978 branch regression relationships. Fert. + Thin. treatment.

Crown position		a	b	r^2	RMS	n
1973	+	2.53774	0.84822	0.975	0.0027	9
	−	2.23409	0.95109	0.960	0.0105	9
1974	+	1.88502	1.06255	0.979	0.0067	11
	−	1.67192	1.14542	0.982	0.0088	12
1975	+	1.90476	1.04004	0.954	0.0138	14
	−	1.61206	1.14480	0.984	0.0059	10
1976	+	1.41405	1.20987	0.961	0.0160	11
	−	1.64761	1.09817	0.984	0.0047	10
1977	+	1.52880	1.14839	0.995	0.0016	13
	−	1.08269	1.29102	0.979	0.0061	14
1978	+	1.41280	1.14478	0.977	0.0044	11
	−	0.81911	1.34922	0.972	0.0121	10

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−5.50835	3.12737	0.897	0.1642	9
	−	−2.31910	2.27444	0.982	0.0262	9
1974	+	−2.36171	2.30679	0.974	0.0393	11
	−	−2.18271	2.34087	0.994	0.0113	12
1975	+	−1.41956	2.06838	0.980	0.0231	14
	−	−1.77119	2.24571	0.991	0.0120	10
1976	+	−2.52736	2.42758	0.983	0.0279	11
	−	−1.27370	2.02947	0.983	0.0171	10
1977	+	−1.49351	2.08602	0.991	0.0099	13
	−	−1.92557	2.22188	0.977	0.0202	14
1978	+	−1.26665	1.87277	0.970	0.0152	11
	−	−1.68442	1.94110	0.909	0.0867	10

Branch Foliar Weight

Crown position		a	b	r^2	RMS	n
1973	+	−3.86992	2.88222	0.998	0.0021	9
	−	−3.74858	2.85912	0.997	0.0057	9
1974	+	−3.90021	2.90980	0.995	0.0127	11
	−	−3.84845	2.91412	0.995	0.0144	12
1975	+	−3.96927	2.94499	0.995	0.0119	14
	−	−4.26631	3.06745	0.996	0.0109	10
1976	+	−4.26428	3.02975	0.998	0.0058	11
	−	−4.18450	3.01876	0.996	0.0090	10
1977	+	−3.89992	2.88092	0.994	0.0115	13
	−	−4.31760	3.01277	0.976	0.0379	14
1978	+	−3.21288	2.53125	0.958	0.0395	11
	−	−2.88345	2.37255	0.979	0.0274	10

Branch Wood Weight

Crown position		a	b	r^2	RMS	n
1973	+	−3.76390	2.96207	0.987	0.0173	9
	−	−2.51686	2.62980	0.995	0.0100	9
1974	+	−2.61222	2.66937	0.990	0.0206	11
	−	−2.44360	2.66889	0.996	0.0090	12
1975	+	−2.07108	2.53533	0.995	0.0081	14
	−	−2.25902	2.63659	0.995	0.0101	10
1976	+	−2.96439	2.81923	0.992	0.0181	11
	−	−1.95987	2.50230	0.995	0.0080	10
1977	+	−1.91175	2.45199	0.995	0.0077	13
	−	−2.39330	2.60623	0.981	0.0228	14
1978	+	−1.65574	2.24724	0.984	0.0112	11
	−	−1.89680	2.27019	0.954	0.0578	10

Branch Total Weight

Appendix 26. August 1979 branch regression relationships. Control treatment.

continued. . .

Crown position		a	b	r^2	RMS	n
1973	+	3.13417	0.67241	0.928	0.0047	7
	−	2.31411	0.92825	0.960	0.0082	9
1974	+	2.16789	0.96078	0.976	0.0083	15
	−	1.83132	1.06235	0.954	0.0263	12
1975	+	2.11516	0.95821	0.973	0.0071	11
	−	1.72253	1.05257	0.972	0.0175	15
1976	+	2.09433	0.95725	0.983	0.0046	14
	−	1.42061	1.16995	0.979	0.0093	10
1977	+	1.40280	1.19023	0.961	0.0102	15
	−	0.71503	1.41497	0.979	0.0084	15
1978	+	1.27871	1.18268	0.978	0.0068	14
	−	0.94932	1.29004	0.989	0.0034	11

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−1.65068	2.04099	0.920	0.0407	8
	−	−5.39141	3.20248	0.983	0.0393	9
1974	+	−3.04081	2.56576	0.984	0.0377	15
	−	−2.23227	2.43950	0.996	0.0122	12
1975	+	−1.33905	2.05842	0.969	0.0378	11
	−	−0.94296	1.97008	0.990	0.0203	15
1976	+	−0.58136	1.81957	0.990	0.0098	14
	−	−0.81703	1.89694	0.989	0.0123	10
1977	+	−1.28414	2.02374	0.972	0.0207	15
	−	−2.06520	2.27594	0.989	0.0109	15
1978	+	−1.17584	1.84919	0.955	0.0343	14
	−	−1.73921	1.96097	0.979	0.0152	11

Branch Foliar Weight

Crown position		a	b	r^2	RMS	n
1973	+	−2.74986	2.52360	0.979	0.0154	8
	−	−3.02361	2.59527	0.974	0.0416	9
1974	+	−3.73794	2.84618	0.997	0.0076	15
	−	−3.12400	2.65911	0.980	0.0699	12
1975	+	−3.79428	2.85192	0.995	0.0106	11
	−	−3.08904	2.61311	0.989	0.0408	15
1976	+	−3.36688	2.69651	0.996	0.0085	14
	−	−3.10210	2.58713	0.972	0.0609	10
1977	+	−3.81616	2.82932	0.976	0.0350	15
	−	−4.35623	3.03930	0.990	0.0186	15
1978	+	−3.42353	2.62266	0.989	0.0170	14
	−	−2.82063	2.37444	0.984	0.0167	11

Branch Wood Weight

Crown position		a	b	r^2	RMS	n
1973	+	−1.66512	2.33953	0.969	0.0193	8
	−	−3.42519	2.88067	0.984	0.0303	9
1974	+	−2.90464	2.77227	0.994	0.0176	15
	−	−2.13016	2.60225	0.998	0.0069	12
1975	+	−1.84678	2.44995	0.989	0.0191	11
	−	−1.27937	2.28458	0.993	0.0145	15
1976	+	−1.07686	2.19515	0.993	0.0101	14
	−	−1.11793	2.19596	0.985	0.0229	10
1977	+	−1.74512	2.39057	0.979	0.0223	15
	−	−2.50440	2.65439	0.995	0.0075	15
1978	+	−1.62697	2.24441	0.985	0.0166	14
	−	−1.91965	2.29449	0.994	0.0057	11

Branch Total Weight

Appendix 26. August 1979 branch regression relationships. Fertilized treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.50399	0.87270	0.959	0.0048	7
	−	1.82656	1.08246	0.981	0.0102	10
1974	+	2.18936	0.95087	0.986	0.0031	12
	−	2.21726	0.93032	0.962	0.0130	16
1975	+	2.07634	0.97213	0.964	0.0091	14
	−	1.76098	1.05663	0.982	0.0111	11
1976	+	1.84486	1.04685	0.976	0.0060	13
	−	1.08035	1.31084	0.979	0.0170	9
1977	+	2.01482	0.97102	0.987	0.0030	13
	−	0.27936	1.62646	0.983	0.0083	10
1978	+	1.08696	1.25228	0.965	0.0107	13
	−	0.06240	1.63080	0.972	0.0107	10

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−7.95986	4.05622	0.976	0.0599	7
	−	−2.40413	2.36478	0.980	0.0508	10
1974	+	−2.55464	2.40048	0.996	0.0065	12
	−	−1.93474	2.27340	0.986	0.0271	16
1975	+	−1.47669	2.10277	0.981	0.0224	14
	−	−0.89541	1.88815	0.989	0.0212	11
1976	+	−1.27295	2.02454	0.990	0.0096	13
	−	−1.36360	2.05128	0.993	0.0134	9
1977	+	−0.59806	1.79700	0.988	0.0096	13
	−	−2.32664	2.44145	0.981	0.0216	10
1978	+	−0.84669	1.67499	0.980	0.0105	13
	−	−2.92921	2.39314	0.975	0.0204	10

Branch Foliar Weight

Crown position		a	b	r^2	RMS	n
1973	+	−3.37648	2.76151	0.998	0.0021	7
	−	−3.53344	2.78004	0.993	0.0235	10
1974	+	−3.74047	2.84445	0.998	0.0049	12
	−	−3.69421	2.83739	0.999	0.0044	16
1975	+	−3.51131	2.77443	0.989	0.0216	14
	−	−3.43200	2.71189	0.998	0.0095	11
1976	+	−3.70104	2.82043	0.995	0.0082	13
	−	−3.09515	2.57194	0.984	0.0493	9
1977	+	−2.81953	2.51035	0.983	0.0271	13
	−	−3.91320	2.82555	0.972	0.0423	10
1978	+	−3.41773	2.61529	0.985	0.0191	13
	−	−4.03548	2.82891	0.996	0.0043	10

Branch Wood Weight

Crown position		a	b	r^2	RMS	n
1973	+	−4.35155	3.22829	0.993	0.0105	7
	−	−2.43988	2.62640	0.991	0.0287	10
1974	+	−2.56565	2.65902	0.997	0.0049	12
	−	−2.18057	2.57615	0.995	0.0136	16
1975	+	−1.84027	2.45384	0.988	0.0192	14
	−	−1.46909	2.30985	0.997	0.0087	11
1976	+	−1.75616	2.41244	0.996	0.0057	13
	−	−1.68079	2.37263	0.998	0.0063	9
1977	+	−0.91112	2.11957	0.989	0.0128	13
	−	−2.60638	2.72357	0.986	0.0191	10
1978	+	−1.45279	2.14916	0.990	0.0085	13
	−	−3.18052	2.75666	0.990	0.0113	10

Branch Total Weight

Appendix 26. August 1979 branch regression relationships. Thinned treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.50567	0.87554	0.910	0.0178	6
	−	1.59591	1.14512	0.979	0.0247	7
1974	+	2.72855	0.77406	0.954	0.0051	14
	−	1.70018	1.10701	0.945	0.0416	11
1975	+	2.27564	0.88623	0.969	0.0102	15
	−	2.15161	0.91545	0.983	0.0053	10
1976	+	2.20771	0.89433	0.984	0.0029	14
	−	1.46995	1.09365	0.985	0.0076	13
1977	+	1.64546	1.06607	0.961	0.0064	12
	−	0.71867	1.34905	0.989	0.0059	12
1978	+	0.89167	1.27819	0.981	0.0057	12
	−	0.31379	1.48976	0.968	0.0113	11

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−3.95740	2.74203	0.936	0.1210	6
	−	−1.65313	2.03120	0.987	0.0452	7
1974	+	−3.03733	2.58452	0.979	0.0258	14
	−	−1.68406	2.21506	0.988	0.0357	11
1975	+	−1.84793	2.22098	0.988	0.0245	15
	−	−1.15286	2.02428	0.996	0.0058	10
1976	+	−0.71738	1.85417	0.978	0.0169	14
	−	−1.73435	2.20231	0.990	0.0209	13
1977	+	−1.19250	2.00083	0.935	0.0386	12
	−	−1.01662	1.85826	0.946	0.0563	12
1978	+	−0.99308	1.76989	0.949	0.0300	12
	−	−2.50520	2.20728	0.942	0.0462	11

Branch Foliar Weight

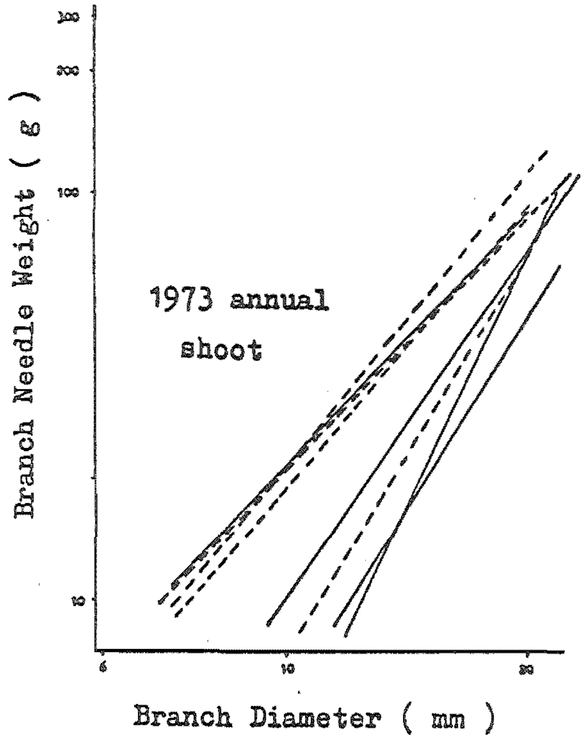
Crown position		a	b	r^2	RMS	n
1973	+	−3.26705	2.68255	0.987	0.0225	6
	−	−3.20726	2.66345	0.999	0.0036	7
1974	+	−3.45615	2.76814	0.996	0.0049	14
	−	−3.18729	2.68038	0.996	0.0174	11
1975	+	−3.80846	2.84522	0.996	0.0116	15
	−	−3.56742	2.75195	0.997	0.0083	10
1976	+	−3.55433	2.73493	0.995	0.0084	14
	−	−3.93766	2.82231	0.996	0.0138	13
1977	+	−3.93962	2.84342	0.989	0.0127	12
	−	−4.28602	2.92434	0.993	0.0182	12
1978	+	−4.08385	2.82686	0.992	0.0108	12
	−	−3.19616	2.46330	0.944	0.0558	11

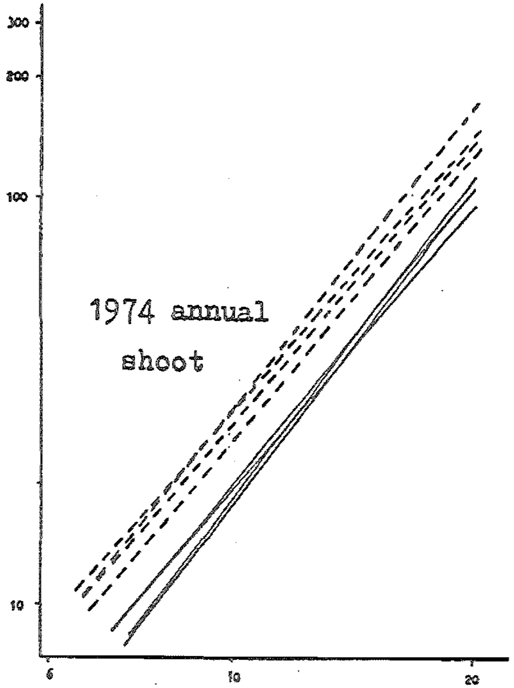
Branch Wood Weight

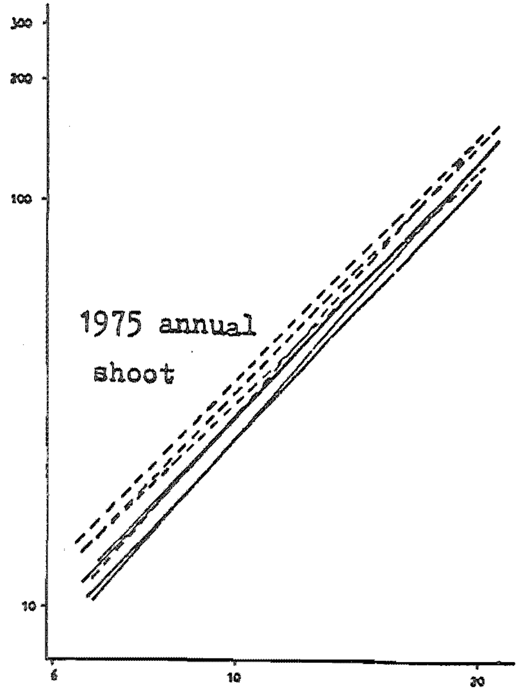
Crown position		a	b	r^2	RMS	n
1973	+	−2.98095	2.74170	0.975	0.0449	6
	−	−2.01128	2.44422	0.998	0.0114	7
1974	+	−2.63452	2.70171	0.991	0.0116	14
	−	−1.90513	2.50443	0.993	0.0248	11
1975	+	−2.17328	2.54771	0.995	0.0138	15
	−	−1.53903	2.35106	0.997	0.0067	10
1976	+	−1.31563	2.25816	0.990	0.0108	14
	−	−2.05552	2.49063	0.995	0.0124	13
1977	+	−1.71859	2.37484	0.977	0.0182	12
	−	−1.78732	2.34314	0.987	0.0204	12
1978	+	−1.73421	2.26130	0.991	0.0077	12
	−	−2.58969	2.49959	0.960	0.0405	11

Branch Total Weight

Appendix 26. August 1979 branch regression relationships. Fert. + Thin. treatment.

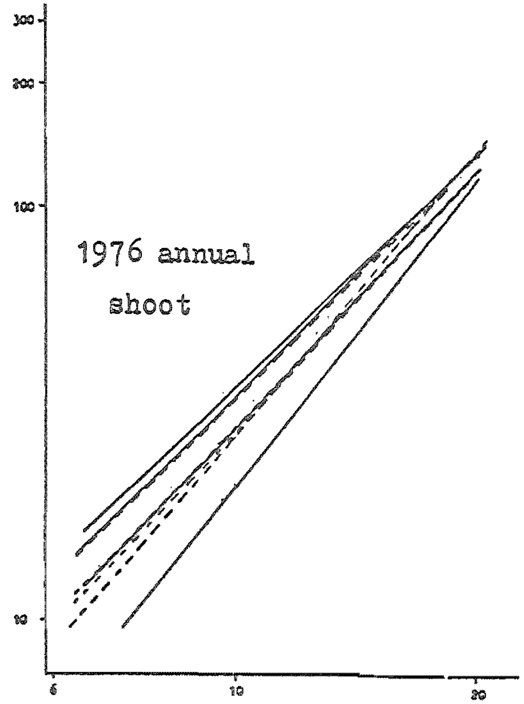


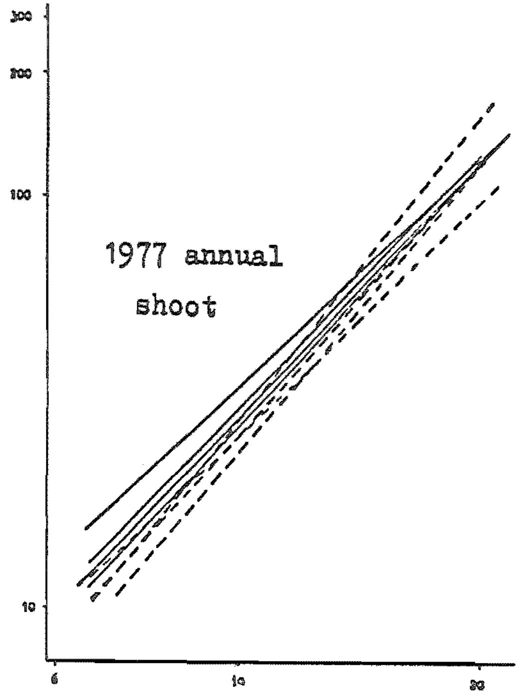




Appendix 27.

August 1979 foliar weight regressions by basal (———) and non-basal (------) clusters.





Crown position		a	b	r^2	RMS	n
1973	+	2.82371	0.74118	0.945	0.0037	15
	−	2.11538	0.96989	0.915	0.0100	15
1974	+	2.05692	0.99690	0.923	0.0109	15
	−	1.89389	1.07156	0.951	0.0126	15
1975	+	2.40134	0.88275	0.897	0.0057	15
	−	2.02132	1.00213	0.944	0.0042	15
1976	+	2.09452	0.97508	0.978	0.0154	18
	−	0.38169	1.58679	0.957	0.0185	15
1977	+	0.79919	1.37967	0.778	0.0263	15
	−	0.83171	1.26996	0.817	0.0162	14

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−1.13795	1.98760	0.910	0.0455	15
	−	−1.81559	2.25127	0.961	0.0238	15
1974	+	−1.61763	2.12862	0.951	0.0310	15
	−	−1.63928	2.15230	0.943	0.0604	15
1975	+	−1.13876	1.97974	0.900	0.0269	15
	−	−1.24699	1.96286	0.938	0.0180	15
1976	+	−0.54292	1.62681	0.900	0.0244	18
	−	−3.65002	2.67261	0.965	0.0431	15
1977	+	−3.73806	2.85447	0.856	0.0655	15
	−	−1.79905	1.48621	0.625	0.0591	14

Branch Foliar Weight

1973	+	−3.33492	2.69630	0.986	0.0123	15
	−	−4.46423	3.08044	0.990	0.0115	15
1974	+	−3.87419	2.85799	0.984	0.0172	15
	−	−3.85641	2.88455	0.992	0.0151	15
1975	+	−3.72199	2.83527	0.962	0.0200	15
	−	−3.70868	2.81551	0.992	0.0047	15
1976	+	−3.80022	2.83366	0.978	0.0154	18
	−	−5.01231	3.25154	0.974	0.0471	15
1977	+	−4.54588	2.98749	0.894	0.0509	15
	−	−2.86441	2.12000	0.844	0.0372	14

Branch Wood Weight

1973	+	−1.58388	2.35687	0.969	0.0206	15
	−	−2.26475	2.60595	0.982	0.0143	15
1974	+	−2.06480	2.49915	0.980	0.0161	15
	−	−2.06256	2.52494	0.980	0.0282	15
1975	+	−1.71129	2.39977	0.959	0.0155	15
	−	−1.74441	2.37406	0.982	0.0073	15
1976	+	−1.49280	2.23747	0.975	0.0107	18
	−	−4.05223	3.11456	0.978	0.0361	15
1977	+	−3.73806	2.85447	0.857	0.0655	15
	−	−2.39346	2.10520	0.805	0.0478	14

Branch Total Weight

Appendix 28. December 1977 branch regression relationships. Control treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.38600	5.08055	0.950	0.0068	15
	-	2.53515	0.83427	0.888	0.0133	15
1974	+	2.77380	0.76847	0.869	0.0086	15
	-	1.86475	1.07678	0.983	0.0053	15
1975	+	2.21997	0.95767	0.952	0.0067	15
	-	1.51125	1.19600	0.966	0.0067	12
1976	+	1.86494	1.05256	0.970	0.0036	21
	-	0.99106	1.38791	0.781	0.0186	14
1977	+	0.16045	1.63531	0.782	0.0102	15
	-	0.45651	1.43689	0.701	0.0397	14

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	-1.53586	2.13338	0.954	0.0369	15
	-	-1.73680	2.24621	0.974	0.0202	15
1974	+	-0.83686	1.88960	0.933	0.0249	15
	-	-1.77480	2.19394	0.979	0.0274	15
1975	+	-0.37112	1.69166	0.935	0.0290	15
	-	-2.22206	2.37396	0.955	0.0355	12
1976	+	-1.47729	1.99745	0.964	0.0152	21
	-	-5.03532	3.34274	0.858	0.0641	14
1977	+	-3.88861	2.58415	0.556	0.0734	15
	-	-3.59388	2.37143	0.835	0.0520	14

Branch Foliar Weight

1973	+	-3.42577	2.72724	0.988	0.0152	15
	-	-4.09149	2.96418	0.989	0.0153	15
1974	+	-3.12334	2.62227	0.977	0.0159	15
	-	-4.10245	2.93649	0.992	0.0192	15
1975	+	-3.47171	2.73554	0.983	0.0188	15
	-	-4.36131	3.07536	0.974	0.0334	12
1976	+	-3.82100	2.83913	0.974	0.0219	21
	-	-5.42677	3.48360	0.910	0.0413	14
1977	+	-5.81056	3.48429	0.889	0.0208	15
		-3.02069	2.17637	0.840	0.0422	14

Branch Wood Weight

1973	+	-1.76245	2.42416	0.984	0.0165	15
	-	-2.10119	2.56799	0.984	0.0166	15
1974	+	-1.25689	2.24702	0.967	0.0166	15
	-	-2.17542	2.54367	0.989	0.0191	15
1975	+	-1.05998	2.16035	0.974	0.0182	15
	-	-2.53226	2.70115	0.973	0.0257	12
1976	+	-1.97004	2.42284	0.985	0.0089	21
	-	-4.83925	3.52644	0.891	0.0525	14
1977	+	-4.64134	3.22185	0.803	0.0350	15
	-	-3.55978	2.65974	0.859	0.0543	14

Branch Total Weight

Appendix 28. December 1977 branch regression relationships. Fertilized treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.37205	0.90012	0.955	0.0069	15
	−	1.97718	1.01598	0.978	0.0056	15
1974	+	2.34854	0.90618	0.903	0.0098	15
	−	2.03940	0.99976	0.950	0.0094	15
1975	+	2.60113	0.81907	0.938	0.0056	15
	−	1.62709	1.16189	0.918	0.0102	15
1976	+	1.86009	1.04607	0.925	0.0069	20
	−	0.91420	1.37203	0.945	0.0207	15
1977	+	1.05682	1.25972	0.885	0.0119	15
	−	−0.61915	1.93844	0.640	0.0236	14

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−2.42037	2.40451	0.966	0.0364	15
	−	−2.63182	2.52667	0.964	0.0570	15
1974	+	−0.96956	1.89943	0.957	0.0181	15
	−	−2.47020	2.41693	0.947	0.0582	15
1975	+	−0.76516	1.83358	0.957	0.0190	15
	−	−1.95971	2.21045	0.917	0.0376	15
1976	+	−0.74308	1.70189	0.891	0.0279	20
	−	−3.34702	2.49311	0.927	0.0921	15
1977	+	−2.80195	2.10938	0.755	0.0836	15
	−	−2.88437	1.98097	0.300	0.1026	14

Branch Foliar Weight

1973	+	−3.37146	2.72636	0.961	0.0535	15
	−	−4.13142	2.95700	0.974	0.0569	15
1974	+	−3.64856	2.78613	0.985	0.0130	15
	−	−3.36852	2.69990	0.950	0.0689	15
1975	+	−2.91003	2.53430	0.968	0.0266	15
	−	−4.50741	3.11418	0.966	0.0290	15
1976	+	−3.31814	2.61137	0.938	0.0354	20
	−	−3.78438	2.72167	0.960	0.0587	15
1977	+	−3.68617	2.55708	0.862	0.0601	15
	−	−6.56034	3.81118	0.741	0.0567	14

Branch Wood Weight

1973	+	−2.31388	2.60253	0.978	0.0269	15
	−	−2.58468	2.71401	0.988	0.0220	15
1974	+	−1.56210	2.32617	0.980	0.0121	15
	−	−2.19316	2.54700	0.986	0.0160	15
1975	+	−1.09731	2.16920	0.976	0.0149	15
	−	−2.49746	2.64497	0.954	0.0287	15
1976	+	−1.33447	2.15481	0.935	0.0253	20
	−	−3.31473	2.76571	0.956	0.0669	15
1977	+	−2.89507	2.46155	0.888	0.0440	15
	−	−4.98914	3.29455	0.617	0.0753	14

Branch Total Weight

Appendix 28. December 1977 branch regression relationships. Thinned treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.60730	0.81910	0.938	0.0079	15
	-	2.17178	0.96168	0.961	0.0070	15
1974	+	2.32269	0.90983	0.956	0.0053	15
	-	2.05852	0.98511	0.962	0.0064	15
1975	+	2.28122	0.93819	0.964	0.0041	15
	-	1.81796	1.07589	0.965	0.0076	15
1976	+	2.37379	0.87291	0.954	0.0046	21
	-	1.08580	1.31898	0.917	0.0249	15
1977	+	0.65467	1.39892	0.924	0.0170	15
	-	0.36255	1.43468	0.718	0.0331	14

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	-1.25175	2.01909	0.950	0.0384	15
	-	-1.72689	2.21764	0.981	0.0179	15
1974	+	-1.13678	1.97142	0.956	0.0251	15
	-	-1.50227	2.10323	0.964	0.0272	15
1975	+	-1.03477	1.94277	0.953	0.0230	15
	-	-1.18315	1.95058	0.953	0.0336	15
1976	+	-1.13993	1.85385	0.874	0.0620	21
	-	-2.95130	2.43064	0.893	0.1128	15
1977	+	-3.19207	2.78939	0.813	0.1281	15
	-	-3.68345	2.29655	0.680	0.1019	14

Branch Foliar Weight

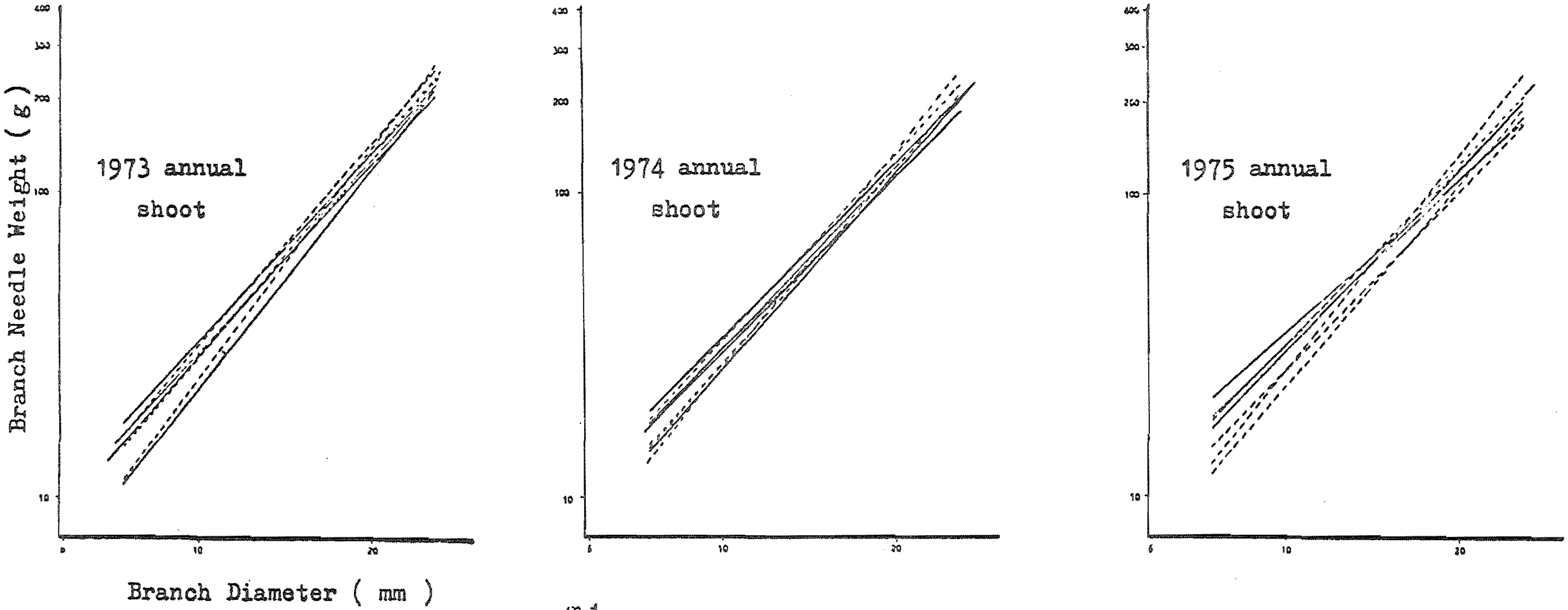
1973	+	-3.01737	2.58250	0.989	0.0128	15
	-	-3.93039	2.89015	0.984	0.0247	15
1974	+	-3.94659	2.86729	0.981	0.0227	15
	-	-3.82253	2.82559	0.981	0.0253	15
1975	+	-3.68443	2.80974	0.992	0.0079	15
	-	-3.40740	2.67644	0.986	0.0176	15
1976	+	-3.21130	2.61275	0.935	0.0596	21
	-	-4.04863	2.86442	0.943	0.0790	15
1977	+	-4.51990	2.90701	0.955	0.0424	15
	-	-3.70488	2.45139	0.782	0.0685	14

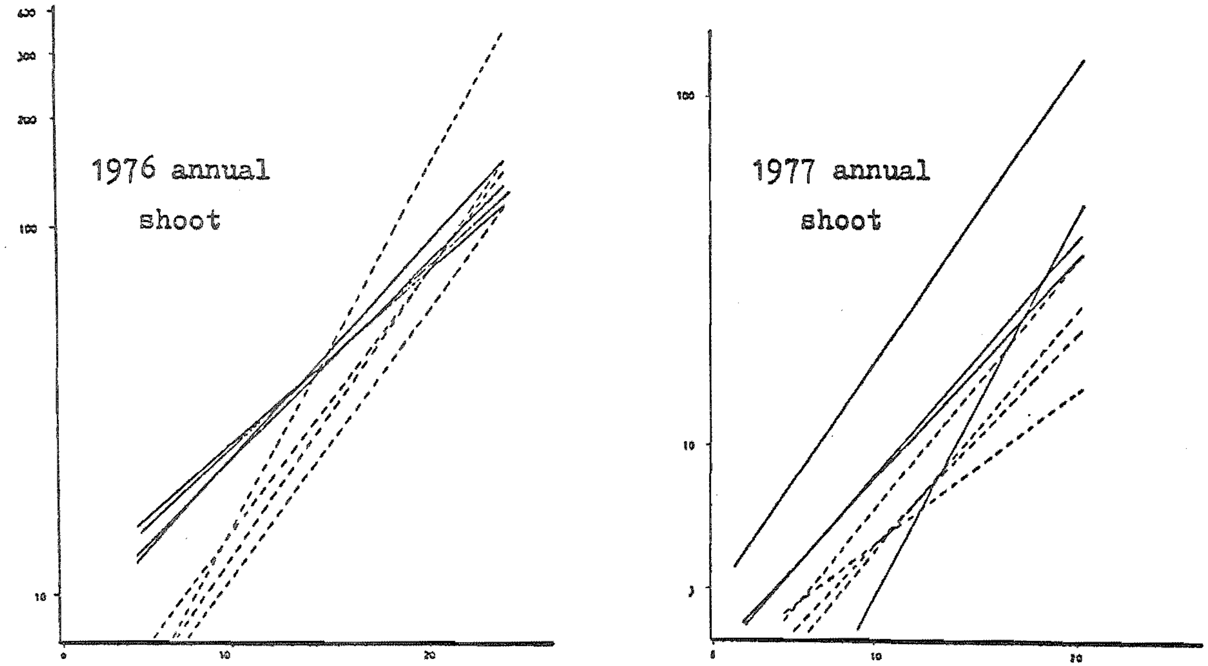
Branch Wood Weight

1973	+	-1.42073	2.29473	0.977	0.0224	15
	-	-2.02546	2.51911	0.987	0.0160	15
1974	+	-1.74229	2.38690	0.977	0.0192	15
	-	-1.87460	2.43406	0.978	0.0223	15
1975	+	-1.58076	2.34902	0.983	0.0115	15
	-	-1.55928	2.29943	0.978	0.0209	15
1976	+	-1.42225	2.21249	0.948	0.0332	21
	-	-3.12176	2.76087	0.923	0.1014	15
1977	+	-3.65462	2.68396	0.934	0.0582	15
	-	-3.83412	2.70164	0.782	0.8331	14

Branch Total Weight

Appendix 28. December 1977 branch regression relationships. Fert. + Thin. treatment.





Appendix 29.

December 1977 foliar weight regressions by basal (——) and non-basal (- - - - -) clusters.

Crown position		a	b	r^2	RMS	n
1973	+	2.21242	0.94542	0.904	0.0078	15
	−	2.82866	0.71201	0.554	0.0480	15
1974	+	2.24367	0.94244	0.926	0.0111	15
	−	1.81397	1.09435	0.944	0.0074	15
1975	+	2.00734	1.01381	0.958	0.0069	15
	−	1.78757	1.08284	0.951	0.0079	15
1976	+	2.77721	0.74337	0.831	0.0058	21
	−	0.51097	1.55630	0.961	0.0116	14
1977	+	1.26944	1.19168	0.769	0.0277	15
	−	0.79242	1.35556	0.887	0.0221	15

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−2.62219	2.47809	0.902	0.0543	15
	−	−1.10379	1.99785	0.883	0.0618	15
1974	+	−1.40494	2.10441	0.923	0.0579	15
	−	−1.94288	2.29744	0.962	0.0220	15
1975	+	−1.21540	2.06106	0.971	0.9710	15
	−	−1.15250	1.98605	0.965	0.0188	15
1976	+	−0.40922	1.69921	0.872	0.0219	21
	−	−2.47531	2.47080	0.936	0.0488	14
1977	+	−1.19151	1.77562	0.831	0.0417	15
	−	−3.05516	2.36393	0.898	0.0602	15

Branch Foliar Weight

1973	+	−4.65298	3.13171	0.944	0.0473	15
	−	−3.37464	2.71572	0.984	0.0139	15
1974	+	−3.54976	2.76857	0.972	0.0342	15
	−	−4.50809	3.12055	0.989	0.0117	15
1975	+	−3.85250	2.88765	0.986	0.0183	15
	−	−3.93014	2.91051	0.985	0.0169	15
1976	+	−1.87529	2.17427	0.898	0.0276	21
	−	−5.02415	3.31963	0.980	0.0267	14
1977	+	−4.18395	4.88853	0.936	0.0370	15
	−	−3.41811	2.53155	0.960	0.0250	15

Branch Wood Weight

1973	+	−2.96667	2.81232	0.929	0.0491	15
	−	−1.47323	2.33425	0.950	0.0334	15
1974	+	−1.68900	2.40788	0.961	0.0363	15
	−	−2.42560	2.67412	0.980	0.0153	15
1975	+	−1.64191	2.40923	0.984	0.0144	15
	−	−1.74354	2.41389	0.984	0.0126	15
1976	+	−0.41045	1.92194	0.899	0.0215	21
	−	−2.92252	2.84583	0.965	0.0341	14
1977	+	−1.93727	2.30559	0.911	0.0339	15
	−	−2.97568	2.61098	0.949	0.0347	15

Branch Total Weight

Appendix 30. March 1978 branch regression relationships. Control treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.27859	0.91410	0.889	0.0155	15
	−	2.45840	0.86453	0.887	0.0061	15
1974	+	2.39201	0.87844	0.925	0.0104	15
	−	1.93462	1.04031	0.968	0.0064	15
1975	+	2.59621	0.82289	0.895	0.0078	15
	−	2.02776	0.97789	0.886	0.0098	15
1976	+	1.64260	1.12500	0.966	0.0054	21
	−	1.92292	0.99585	0.915	0.0143	14
1977	+	1.21292	1.17727	0.891	0.0108	15
	−	0.22204	1.00903	0.741	0.0593	15

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−1.88256	2.26580	0.973	0.0208	15
	−	−1.75826	2.26723	0.889	0.0413	15
1974	+	−2.11061	2.35997	0.980	0.0186	15
	−	−1.58132	2.21267	0.969	0.0285	15
1975	+	−1.21363	2.07806	0.969	0.0135	15
	−	−1.28560	2.11495	0.908	0.0362	15
1976	+	−0.83318	1.92055	0.344	0.0268	21
	−	−1.84420	2.24187	0.957	0.0353	14
1977	+	−3.55175	2.66825	0.682	0.2117	15
	−	−3.74062	2.71366	0.781	0.1350	15

Branch Foliar Weight

1973	+	−3.54160	2.79120	0.988	0.0140	15
	−	−3.54477	2.79709	0.969	0.0163	15
1974	+	−3.63584	2.80002	0.990	0.0136	15
	−	−3.99035	2.92569	0.975	0.0398	15
1975	+	−3.65406	2.83793	0.982	0.0143	15
	−	−3.75537	2.85912	0.956	0.0302	15
1976	+	−4.75585	3.18831	0.973	0.0350	21
	−	−3.81969	2.83501	0.973	0.0352	14
1977	+	−4.09710	2.79672	0.957	0.0225	15
	−	−3.23530	2.42217	0.903	0.0412	15

Branch Wood Weight

1973	+	−2.01708	2.52777	0.985	0.0142	15
	−	−1.91153	2.51806	0.940	0.0258	15
1974	+	−2.16039	2.57480	0.989	0.0134	15
	−	−1.95238	2.52767	0.981	0.0225	15
1975	+	−1.59716	2.41186	0.981	0.0092	15
	−	−1.63279	2.42402	0.944	0.0281	15
1976	+	−1.43102	2.32463	0.975	0.0170	21
	−	−2.13253	2.54065	0.970	0.0311	14
1977	+	−3.16150	2.74544	0.882	0.0644	15
	−	−3.37961	2.80334	0.837	0.1004	15

Branch Total Weight

Appendix 30. March 1978 branch regression relationships. Fertilized treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.67114	0.78748	0.835	0.0117	14
	−	1.64118	1.14608	0.970	0.0061	13
1974	+	2.73586	0.76262	0.919	0.0064	15
	−	1.87346	1.03859	0.962	0.0063	14
1975	+	2.38125	0.88905	0.902	0.0076	15
	−	2.44036	0.82516	0.946	0.0020	13
1976	+	2.13472	0.93726	0.920	0.0046	21
	−	1.20528	1.21997	0.936	0.0191	13
1977	+	1.25187	1.16456	0.816	0.0111	13
	−	0.83956	1.31713	0.890	0.0239	15

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−1.44604	2.11039	0.935	0.0297	14
	−	−1.96902	2.30203	0.977	0.0183	13
1974	+	−1.99744	2.27894	0.976	0.0157	15
	−	−1.61668	2.17321	0.959	0.0290	14
1975	+	−0.42295	1.75087	0.914	0.0256	15
	−	−2.86818	2.59135	0.827	0.0715	13
1976	+	−0.86293	1.87480	0.921	0.0181	21
	−	−1.64835	2.04835	0.977	0.0183	13
1977	+	0.23089	1.21550	0.457	0.0638	13
	−	−3.12704	2.38398	0.790	0.1683	15

Branch Foliar Weight

Crown position		a	b	r^2	RMS	n
1973	+	−3.33438	2.71183	0.978	0.0160	14
	−	−4.32664	3.04994	0.984	0.0222	13
1974	+	−3.84749	2.85650	0.976	0.0244	15
	−	−3.74000	2.81483	0.978	0.0261	14
1975	+	−3.44396	2.73160	0.962	0.0259	15
	−	−4.29822	2.98450	0.785	0.1239	13
1976	+	−3.41235	2.65753	0.800	0.1059	21
	−	−4.26066	2.89565	0.962	0.0618	13
1977	+	−4.05672	2.72757	0.700	0.1160	13
	−	−3.19499	2.37749	0.887	0.8031	15

Branch Wood Weight

Crown position		a	b	r^2	RMS	n
1973	+	−1.72671	2.42093	0.965	0.0203	14
	−	−2.31809	2.62849	0.982	0.0182	13
1974	+	−2.22418	2.56630	0.979	0.0179	15
	−	−1.85430	2.45069	0.973	0.0238	14
1975	+	−1.11026	2.19940	0.953	0.0211	15
	−	−2.85900	2.78005	0.824	0.0839	13
1976	+	−1.27463	2.21291	0.907	0.0302	21
	−	−2.18454	2.44944	0.979	0.0248	13
1977	+	−1.16684	1.95320	0.643	0.0768	13
	−	−2.99573	2.58306	0.855	0.1266	15

Branch Total Weight

Appendix 30. March 1978 branch regression relationships. Thinned treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.74870	0.77898	0.844	0.0093	15
	−	2.51209	0.84441	0.922	0.0101	15
1974	+	2.42985	0.87198	0.969	0.0041	15
	−	2.05567	0.97597	0.955	0.0106	15
1975	+	1.96765	1.00702	0.897	0.0066	15
	−	1.75582	1.05016	0.904	0.0138	15
1976	+	2.00342	0.98256	0.939	0.0043	18
	−	0.98950	1.28886	0.870	0.0207	15
1977	+	1.36641	1.11589	0.869	0.0138	15
	−	−0.86285	2.07100	0.763	0.0665	15

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−1.63670	2.21542	0.942	0.0250	15
	−	−1.82797	2.28226	0.969	0.0279	15
1974	+	−1.57856	2.17009	0.955	0.0374	15
	−	−1.18841	2.07845	0.980	0.0212	15
1975	+	−2.05209	2.31709	0.907	0.0310	15
	−	−1.34374	2.09478	0.946	0.0295	15
1976	+	−1.78591	2.20316	0.896	0.0395	18
	−	−1.63547	2.07099	0.866	0.0553	15
1977	+	0.07682	1.32818	0.766	0.0397	15
	−	−4.83155	3.19632	0.755	0.1651	15

Branch Foliar Weight

1973	+	−3.54492	2.79571	0.976	0.0157	15
	−	−3.46636	2.76477	0.963	0.0488	15
1974	+	−3.35321	2.71339	0.985	0.0191	15
	−	−3.53536	2.77391	0.985	0.0277	15
1975	+	−4.44387	3.04103	0.931	0.0384	15
	−	−4.07027	2.91832	0.983	0.0169	15
1976	+	−3.45064	2.69748	0.984	0.0082	18
	−	−4.81594	3.10966	0.953	0.0395	15
1977	+	−3.86267	2.67521	0.945	0.0307	15
	−	−0.86285	2.07100	0.763	0.0665	15

Branch Wood Weight

1973	+	−1.81014	2.47764	0.971	0.0153	15
	−	−1.82589	2.48273	0.980	0.0207	15
1974	+	−1.66616	2.40893	0.991	0.0090	15
	−	−1.48207	2.36745	0.988	0.0154	15
1975	+	−2.49209	2.66037	0.934	0.0284	15
	−	−1.73037	2.41239	0.969	0.0218	15
1976	+	−1.92150	2.45131	0.973	0.0117	18
	−	−2.22929	2.48333	0.942	0.0315	15
1977	+	−0.84905	1.87515	0.909	0.0259	15
	−	−4.79256	3.42824	0.819	0.1291	15

Branch Total Weight

Appendix 30. March 1978 branch regression relationships. Fert. + Thin. treatment.

Crown position		a	b	r^2	RMS	n
1973	+	2.54426	0.63087	0.891	0.0143	15
	–	2.13567	0.97390	0.925	0.0112	14
1974	+	2.36785	0.90177	0.949	0.0057	15
	–	1.91309	1.04420	0.959	0.0079	15
1975	+	2.12036	0.96938	0.935	0.0092	15
	–	1.76295	1.08585	0.967	0.0047	15
1976	+	2.43318	0.84466	0.888	0.0089	21
	–	0.50008	1.49796	0.895	0.0259	15
1977	+	0.96198	1.29406	0.895	0.0158	15
	–	0.05562	1.68188	0.765	0.0459	15

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−2.18689	2.28221	0.948	0.0486	15
	–	−2.32728	2.33618	0.937	0.0531	14
1974	+	−1.15031	1.96715	0.961	0.0203	15
	–	−1.28507	2.06662	0.937	0.0490	15
1975	+	−1.09177	1.96685	0.962	0.0212	15
	–	−0.95003	1.97114	0.934	0.0329	15
1976	+	−0.54761	1.73623	0.889	0.0370	21
	–	−1.79610	2.07051	0.859	0.0688	15
1977	+	−1.43029	1.86360	0.961	0.0115	15
	–	−2.35294	2.12615	0.839	0.0460	15

Branch Foliar Weight

1973	+	−2.99550	2.58167	0.990	0.0116	15
	–	−3.98427	2.90961	0.990	0.0124	14
1974	+	−3.90330	2.86616	0.993	0.0072	15
	–	−3.99447	2.91796	0.990	0.0151	15
1975	+	−3.45948	2.73914	0.985	0.0162	15
	–	−3.67662	2.84213	0.942	0.0588	15
1976	+	−2.99641	2.53738	0.967	0.0218	21
	–	−4.87847	3.15881	0.957	0.0439	15
1977	+	−4.45758	2.94123	0.960	0.0295	15
	–	−3.98932	2.79266	0.895	0.0491	15

Branch Wood Weight

1973	+	−2.02184	2.47276	0.976	0.0253	15
	–	−2.53405	2.64796	0.982	0.0192	14
1974	+	−1.72443	2.38126	0.982	0.0131	15
	–	−1.77011	2.43572	0.974	0.0271	15
1975	+	−1.52517	2.33600	0.989	0.0088	15
	–	−1.47519	2.35985	0.944	0.0392	15
1976	+	−0.99852	2.11033	0.950	0.0232	21
	–	−2.52592	2.57042	0.930	0.0489	15
1977	+	−2.14814	2.36114	0.969	0.0146	15
	–	−2.77950	2.57192	0.891	0.0432	15

Branch Total Weight

Appendix 31. June 1978 branch regression relationships. Control treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.35571	0.86364	0.952	0.0069	15
	−	1.78741	1.08983	0.955	0.0091	15
1974	+	2.33947	0.90696	0.979	0.0043	15
	−	1.95895	1.01897	0.876	0.0102	15
1975	+	1.47182	1.19168	0.919	0.0073	15
	−	1.14447	1.28387	0.906	0.0172	15
1976	+	1.71294	1.07313	0.866	0.0100	21
	−	0.86033	1.33132	0.915	0.0310	15
1977	+	1.46349	1.08986	0.892	0.0093	15
	−	1.21043	1.13453	0.914	0.0079	12

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−2.00539	2.26394	0.956	0.0414	15
	−	−2.01342	2.32652	0.968	0.0290	15
1974	+	−1.35952	2.05633	0.974	0.0270	15
	−	−1.09153	2.01831	0.907	0.0289	15
1975	+	−0.59793	1.80380	0.770	0.0554	15
	−	−2.18109	2.39490	0.940	0.0369	15
1976	+	−0.88685	1.86945	0.896	0.0227	21
	−	−1.96521	2.20207	0.944	0.0546	15
1977	+	−1.31105	1.85206	0.901	0.0244	15
	−	−1.19528	1.67061	0.733	0.0646	12

Branch Foliar Weight

Crown position		a	b	r^2	RMS	n
1973	+	−3.60936	2.78366	0.991	0.0121	15
	−	−4.26694	3.01058	0.993	0.0109	15
1974	+	−3.64549	2.78304	0.991	0.0177	15
	−	−4.33612	3.04234	0.958	0.0284	15
1975	+	−4.18193	2.98264	0.976	0.0129	15
	−	−4.06776	2.92569	0.968	0.0283	15
1976	+	−4.02338	2.87706	0.954	0.0223	21
	−	−4.24032	2.90885	0.969	0.0506	15
1977	+	−4.01054	2.76175	0.950	0.0263	15
	−	−3.50396	2.55081	0.960	0.0176	12

Branch Wood Weight

Crown position		a	b	r^2	RMS	n
1973	+	−2.11355	2.52486	0.990	0.0117	15
	−	−2.33123	2.63143	0.985	0.0169	15
1974	+	−1.71133	2.38863	0.984	0.0219	15
	−	−1.77563	2.44997	0.947	0.0233	15
1975	+	−1.56952	2.35243	0.918	0.0287	15
	−	−2.43639	2.66835	0.956	0.0329	15
1976	+	−1.54204	2.30052	0.958	0.0129	21
	−	−2.42459	2.56527	0.961	0.0502	15
1977	+	−1.95383	2.30299	0.955	0.0161	15
	−	−1.69109	2.11525	0.876	0.0411	12

Branch Total Weight

Appendix 31. June 1978 branch regression relationships. Fertilized treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.67038	0.77753	0.890	0.0116	15
	−	1.87554	1.04555	0.977	0.0058	15
1974	+	2.13170	0.96104	0.952	0.0089	13
	−	1.70582	1.11233	0.862	0.0195	15
1975	+	2.37699	0.87720	0.908	0.0037	14
	−	1.96612	0.99154	0.947	0.0039	15
1976	+	2.28767	0.87302	0.921	0.0043	20
	−	1.68151	1.04993	0.774	0.0165	15
1977	+	1.68886	0.99014	0.792	0.0132	15
	−	1.19707	1.15308	0.870	0.0188	15

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−1.41590	2.05231	0.959	0.0280	15
	−	−1.45042	2.09001	0.947	0.0550	15
1974	+	−1.53786	2.09888	0.950	0.0437	13
	−	−2.24575	2.37373	0.963	0.0216	15
1975	+	−1.02225	1.95458	0.866	0.0281	14
	−	−1.65295	2.16382	0.893	0.0388	15
1976	+	−0.55174	1.75350	0.887	0.0259	20
	−	−2.14481	2.26924	0.833	0.0529	15
1977	+	−1.34914	1.80568	0.749	0.0557	15
	−	−1.53160	1.77605	0.877	0.0418	15

Branch Foliar Weight

1973	+	−2.97723	2.59102	0.988	0.0125	15
	−	−3.61601	2.78555	0.990	0.0175	15
1974	+	−3.72836	2.81643	0.988	0.0184	13
	−	−4.18680	2.96786	0.981	0.0172	15
1975	+	−3.78114	2.84040	0.970	0.0122	14
	−	−4.25973	2.99419	0.979	0.0132	15
1976	+	−3.33324	2.64306	0.944	0.0274	20
	−	−4.57753	3.06118	0.911	0.0474	15
1977	+	−3.66302	2.62808	0.930	0.0278	15
	−	−2.90050	2.30332	0.958	0.0223	15

Branch Wood Weight

1973	+	−1.51806	2.32673	0.981	0.0164	15
	−	−1.84928	2.44525	0.984	0.0222	15
1974	+	−1.91734	2.45127	0.976	0.0280	13
	−	−2.48251	2.65866	0.981	0.0133	15
1975	+	−1.56103	2.34929	0.948	0.0144	14
	−	−2.12892	2.53475	0.959	0.0194	15
1976	+	−1.10471	2.15032	0.928	0.0237	20
	−	−2.58136	2.63412	0.878	0.0498	15
1977	+	−1.85685	2.23078	0.899	0.0288	15
	−	−1.86765	2.17253	0.951	0.0232	15

Branch Total Weight

Appendix 31. June 1978 branch regression relationships. Thinned treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.64481	0.78920	0.938	0.0110	15
	−	2.46102	0.84800	0.895	0.0121	15
1974	+	2.04560	0.99821	0.953	0.0082	15
	−	1.97627	1.00216	0.943	0.0050	15
1975	+	1.85200	1.05631	0.941	0.0072	15
	−	1.11264	1.28536	0.956	0.0085	15
1976	+	2.52426	0.78329	0.948	0.0026	21
	−	0.72047	1.36596	0.916	0.0210	15
1977	+	1.51418	1.05855	0.944	0.0059	14
	−	1.26285	1.10297	0.940	0.0048	14

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−2.44100	2.44170	0.981	0.0318	15
	−	−1.87526	2.27054	0.947	0.0411	15
1974	+	−1.80536	2.22121	0.972	0.0238	15
	−	−1.62338	2.21227	0.988	0.0050	15
1975	+	−1.66480	2.20316	0.977	0.0117	15
	−	−2.17644	2.37855	0.969	0.0204	15
1976	+	−0.47541	1.76659	0.848	0.0433	21
	−	−2.62318	2.45722	0.933	0.0534	15
1977	+	−1.90790	2.09021	0.917	0.0343	14
	−	−1.33220	1.77159	0.883	0.0258	14

Branch Foliar Weight

1973	+	−3.13523	2.63433	0.984	0.0294	15
	−	−3.87059	2.86604	0.988	0.0145	15
1974	+	−4.27146	2.99947	0.993	0.0109	15
	−	−4.13359	2.95431	0.990	0.0073	15
1975	+	−4.38860	3.03770	0.985	0.0144	15
	−	−4.84386	3.18215	0.975	0.0293	15
1976	+	−3.21694	2.59538	0.978	0.0120	21
	−	−5.12611	3.20177	0.963	0.0481	15
1977	+	−3.51158	2.57976	0.983	0.0098	14
	−	−3.47930	2.52385	0.981	0.0076	14

Branch Wood Weight

1973	+	−2.17236	2.56352	0.991	0.0156	15
	−	−2.11290	2.54886	0.978	0.0210	15
1974	+	−2.26203	2.58525	0.988	0.0129	15
	−	−1.95704	2.50878	0.993	0.0036	15
1975	+	−2.17876	2.57189	0.984	0.0111	15
	−	−2.60344	2.71100	0.976	0.0199	15
1976	+	−0.96940	2.12411	0.944	0.0209	21
	−	−3.04289	2.78767	0.963	0.0366	15
1977	+	−2.03164	2.34074	0.976	0.0120	14
	−	−1.74580	2.15522	0.960	0.0120	14

Branch Total Weight

Appendix 31. June 1978 branch regression relationships. Fert. + Thin. treatment.

Crown position		a	b	r^2	RMS	n
1973	+	2.26154	0.92556	0.922	0.0122	11
	−	1.85367	1.09514	0.948	0.0069	12
1974	+	2.24819	0.95904	0.950	0.0119	12
	−	1.92249	1.07296	0.905	0.0131	12
1975	+	2.45661	0.89410	0.936	0.0066	12
	−	1.90694	1.02540	0.902	0.0158	12
1976	+	1.92201	1.03447	0.885	0.0049	12
	−	1.65283	1.12511	0.894	0.0197	11
1977	+	1.84755	1.04979	0.941	0.0067	12
	−	1.27268	1.26821	0.914	0.0057	9
1978	+	2.34299	0.77052	0.404	0.0093	12
	−	0.60138	1.48619	0.722	0.0441	12

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−3.35994	2.50518	0.943	0.0578	11
	−	−2.19799	2.19458	0.718	0.1941	12
1974	+	−2.57608	2.36639	0.878	0.1876	12
	−	−2.00274	2.23704	0.874	0.0779	12
1975	+	−1.96588	2.25944	0.890	0.0769	12
	−	−1.31294	2.07925	0.927	0.0479	12
1976	+	0.49262	1.43891	0.861	0.0117	12
	−	−1.38586	2.08247	0.948	0.0310	11
1977	+	−1.38900	2.03927	0.971	0.0120	12
	−	−1.36381	2.05167	0.952	0.0060	9
1978	+	−1.00830	1.79529	0.732	0.0137	12
	−	−2.67833	2.40605	0.964	0.0117	12

Branch Foliar Weight

1973	+	−3.00210	2.58779	0.976	0.0274	11
	−	−3.98579	2.95316	0.991	0.0080	12
1974	+	−3.53619	2.77536	0.991	0.0162	12
	−	−4.28758	3.05131	0.982	0.0182	12
1975	+	−3.41839	2.74562	0.969	0.0299	12
	−	−3.72253	2.79424	0.897	0.1247	12
1976	+	−3.51787	2.74788	0.959	0.0115	12
	−	−3.93010	2.91279	0.933	0.0801	11
1977	+	−3.76172	2.80239	0.969	0.0243	12
	−	−4.52280	3.11146	0.976	0.0090	9
1978	+	−3.03305	2.39099	0.877	0.0095	12
	−	−2.86579	2.33116	0.865	0.0448	12

Branch Wood Weight

1973	+	−2.26925	2.51487	0.977	0.0255	11
	−	−2.32476	2.57613	0.965	0.0254	12
1974	+	−2.30568	2.57206	0.987	0.0210	12
	−	−2.62930	2.72092	0.967	0.0279	12
1975	+	−1.92554	2.48275	0.955	0.0352	12
	−	−1.59452	2.36302	0.930	0.0587	12
1976	+	−0.82454	2.09646	0.946	0.0088	12
	−	−1.82265	2.44968	0.952	0.0396	11
1977	+	−1.78098	2.38683	0.976	0.0132	12
	−	−1.97356	2.47946	0.980	0.0048	9
1978	+	−1.25195	2.07115	0.919	0.0045	12
	−	−2.46134	2.52754	0.956	0.0159	12

Branch Total Weight

Appendix 32. March 1979 branch regression relationships. Control treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.34938	0.90580	0.854	0.0168	12
	−	1.98699	1.02921	0.936	0.0201	12
1974	+	2.56152	0.84234	0.934	0.0121	11
	−	2.28082	0.93020	0.918	0.0110	12
1975	+	2.29484	0.92890	0.910	0.0214	12
	−	2.01841	1.02162	0.942	0.0051	12
1976	+	1.83921	1.04701	0.958	0.0024	11
	−	1.85197	0.99925	0.977	0.0034	12
1977	+	1.75696	1.04738	0.867	0.0081	12
	−	1.78964	1.00820	0.805	0.0111	11
1978	+	1.83193	0.95458	0.526	0.0102	11
	−	1.60261	0.99154	0.797	0.0119	11

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	−2.59617	2.28735	0.759	0.1962	12
	−	−2.95254	2.52731	0.932	0.1294	12
1974	+	−2.06975	2.28334	0.895	0.1466	11
	−	−1.67991	2.21173	0.975	0.0179	12
1975	+	−1.53155	2.16117	0.983	0.0201	12
	−	−1.11841	2.09235	0.887	0.0438	12
1976	+	−1.44445	2.10255	0.965	0.0080	11
	−	−1.12528	2.03134	0.974	0.0159	12
1977	+	−0.45678	1.73271	0.887	0.0188	12
	−	−1.93727	2.26813	0.807	0.0557	11
1978	+	0.08162	1.35783	0.619	0.0145	11
	−	−4.46700	3.20572	0.828	0.1024	11

Branch Foliar Weight

1973	+	−3.36307	2.71928	0.976	0.0218	12
	−	−3.65364	2.85727	0.989	0.0249	12
1974	+	−3.42280	2.75668	0.984	0.0297	11
	−	−3.62747	2.82139	0.991	0.0100	12
1975	+	−3.71094	2.85576	0.980	0.0420	12
	−	−4.05963	2.99785	0.973	0.0201	12
1976	+	−4.03059	2.90895	0.984	0.0067	11
	−	−4.00944	2.86989	0.996	0.0043	12
1977	+	−3.55025	2.68065	0.957	0.0158	12
	−	−3.73989	2.74899	0.957	0.0155	11
1978	+	−3.37715	2.50015	0.773	0.0241	11
	−	−2.44704	2.07290	0.972	0.0061	11

Branch Wood Weight

1973	+	−2.41599	2.58694	0.969	0.0257	12
	−	−2.87015	2.80707	0.934	0.0363	12
1974	+	−2.08878	2.54199	0.970	0.0452	11
	−	−1.91714	2.50377	0.958	0.0105	12
1975	+	−1.84506	2.48265	0.985	0.0237	12
	−	−1.59821	2.44669	0.944	0.0281	12
1976	+	−1.96790	2.48142	0.984	0.0051	11
	−	−1.55513	2.35006	0.988	0.0094	12
1977	+	−1.15329	2.15749	0.949	0.0123	12
	−	−1.98524	2.45903	0.901	0.0305	11
1978	+	−0.74437	1.85508	0.804	0.0111	11
	−	−3.40797	2.92652	0.913	0.0393	11

Branch Total Weight

Appendix 32. March 1979 branch regression relationships. Fertilized treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.42195	0.87132	0.850	0.0263	12
	-	2.04426	0.98029	0.920	0.0224	12
1974	+	2.34420	0.89933	0.961	0.0102	12
	-	2.26324	0.94104	0.977	0.0036	12
1975	+	2.73452	0.77830	0.904	0.0064	11
	-	1.93624	1.01591	0.960	0.0053	12
1976	+	1.72474	1.08030	0.966	0.0062	12
	-	1.52609	1.14489	0.945	0.0132	12
1977	+	1.52679	1.14513	0.965	0.0058	12
	-	1.11393	1.29702	0.820	0.0251	11
1978	+	1.31961	1.16701	0.711	0.0091	10
	-	0.40344	1.51116	0.825	0.0140	11

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	-2.94246	2.50658	0.905	0.1303	12
	-	-2.17060	2.34727	0.980	0.0308	12
1974	+	-2.56288	2.45726	0.953	0.0927	12
	-	-1.13202	2.03805	0.930	0.0542	12
1975	+	-1.16271	2.00833	0.932	0.0291	11
	-	-0.88343	1.93540	0.936	0.0319	12
1976	+	-1.24160	2.01244	0.956	0.0281	12
	-	-0.98494	1.90989	0.951	0.0322	12
1977	+	-0.98112	1.90990	0.967	0.0156	12
	-	-1.46523	2.02859	0.837	0.0361	11
1978	+	-2.31924	2.29144	0.885	0.0115	10
	-	-3.74551	2.78592	0.863	0.0358	11

Branch Foliar Weight

1973	+	-3.00627	2.60492	0.972	0.0381	12
	-	-3.80644	2.86515	0.990	0.0229	12
1974	+	-3.72837	2.83918	0.991	0.0227	12
	-	-3.50224	2.79968	0.986	0.0194	12
1975	+	-2.99614	2.60701	0.982	0.0127	11
	-	-3.65345	2.79976	0.978	0.0221	12
1976	+	-3.92447	2.86150	0.986	0.0180	12
	-	-4.44130	3.05372	0.986	0.0226	12
1977	+	-3.84904	2.82557	0.981	0.0188	12
	-	-4.68695	3.12026	0.933	0.0481	11
1978	+	-4.37068	2.93038	0.903	0.0156	10
	-	-3.62668	2.61909	0.860	0.0325	11

Branch Wood Weight

1973	+	-2.21839	2.54581	0.957	0.0580	12
	-	-2.32439	2.62132	0.993	0.0129	12
1974	+	-2.52766	2.67225	0.976	0.0555	12
	-	-1.55924	2.39995	0.971	0.0297	12
1975	+	-1.44387	2.32944	0.970	0.0168	11
	-	-1.41928	2.31847	0.965	0.0245	12
1976	+	-1.68468	2.37171	0.975	0.0215	12
	-	-1.70028	2.37567	0.983	0.0169	12
1977	+	-1.49818	2.29320	0.978	0.0144	12
	-	-2.10384	2.47081	0.924	0.0349	11
1978	+	-2.58811	2.58849	0.944	0.0067	10
	-	-3.42826	2.87747	0.883	0.0319	11

Branch Total Weight

Appendix 32. March 1979 branch regression relationships. Thinned treatment.

continued . . .

Crown position		a	b	r^2	RMS	n
1973	+	2.77208	0.77068	0.936	0.0110	11
	-	2.25700	0.94268	0.957	0.0100	12
1974	+	2.62959	0.82102	0.950	0.0098	12
	-	2.91295	0.68251	0.841	0.0173	12
1975	+	2.33364	0.72645	0.943	0.0053	11
	-	1.85342	1.03231	0.952	0.0113	12
1976	+	2.49118	0.81930	0.882	0.0055	10
	-	1.91954	0.98623	0.951	0.0077	11
1977	+	1.98611	0.97084	0.945	0.0067	12
	-	1.99660	0.93307	0.701	0.0123	12
1978	+	0.94377	1.27274	0.857	0.0090	10
	-	0.98387	1.25393	0.834	0.0203	9

Branch Length

Crown position		a	b	r^2	RMS	n
1973	+	-3.47045	2.75555	0.969	0.0670	11
	-	-1.97820	2.21810	0.939	0.0787	12
1974	+	-1.44907	2.14660	0.982	0.0238	12
	-	-1.35807	2.09364	0.983	0.0148	12
1975	+	-1.31959	2.08274	0.951	0.0368	11
	-	-1.47229	2.13314	0.949	0.0514	12
1976	+	-0.63642	1.85609	0.869	0.0320	10
	-	-1.54195	2.14936	0.979	0.0155	11
1977	+	-0.58703	1.79453	0.948	0.0213	12
	-	-0.01521	1.54974	0.800	0.0202	12
1978	+	-0.85999	1.70721	0.566	0.0697	10
	-	-2.16139	2.15824	0.814	0.0688	9

Branch Foliar Weight

1973	+	-3.49750	2.81854	0.994	0.0138	11
	-	-3.29342	2.69669	0.988	0.0220	12
1974	+	-3.40618	2.77613	0.996	0.0078	12
	-	-3.38480	2.73162	0.983	0.0256	12
1975	+	-3.49331	2.75731	0.982	0.0227	11
	-	-3.78240	2.84578	0.978	0.0381	12
1976	+	-3.04536	2.58543	0.958	0.0182	10
	-	-3.81015	2.80276	0.989	0.0136	11
1977	+	-3.26284	2.59740	0.978	0.0187	12
	-	-3.03995	2.52804	0.930	0.0165	12
1978	+	-4.52354	2.91714	0.877	0.0398	10
	-	-3.24716	2.45660	0.981	0.0077	9

Branch Wood Weight

1973	+	-2.66881	2.75643	0.990	0.0217	11
	-	-2.04286	2.49643	0.980	0.0317	12
1974	+	-1.68435	2.44867	0.994	0.0101	12
	-	-1.64164	2.40264	0.985	0.0177	12
1975	+	-1.63811	2.39387	0.971	0.0286	11
	-	-1.79111	2.44368	0.967	0.0427	12
1976	+	-1.09224	2.20425	0.929	0.0231	10
	-	-1.83455	2.43109	0.999	0.0106	11
1977	+	-1.04016	2.13600	0.972	0.0161	12
	-	-0.55454	1.93245	0.904	0.0136	12
1978	+	-1.58336	2.16014	0.736	0.0546	10
	-	-2.16758	2.36734	0.915	0.0344	9

Branch Total Weight

Appendix 32. March 1979 branch regression relationships. Fert. + Thin. treatment.

SOURCE	df	SS	MS	F	P
Blocks	2	0.006	0.003	0.389	ns
Treatments	(3)	1.088	0.0363	46.456	***
Fert	1	0.235	0.235	30.092	***
Thin	1	0.817	0.817	104.697	***
F x T	1	0.036	0.036	4.579	*
(Co-variate)	1				
Error	5	0.039	0.008		
Total	10	1.133			

Treatment Means	C	F	T	F + T
	3.88	4.07	4.32	4.73
P = 0.05	- - - -	- - - -		
P = 0.01	- - - -	- - - -		
		- - - -	- - - -	

Needle weight

SOURCE	df	SS	MS	F	P
Blocks	2	0.142	0.071	0.428	ns
Treatments	(3)	29.863	9.954	59.986	***
Fert	1	6.614	6.614	39.856	***
Thin	1	22.010	22.010	132.634	***
F x T	1	1.240	1.240	7.468	**
(Co-variate)	1				
Error	5	0.830	0.166		
Total	10	30.834			

Treatment Means	C	F	T	F + T
	18.70	19.64	20.88	23.14
P = 0.05				
P = 0.01	- - - -	- - - -		
		- - - -	- - - -	

Total weight

Appendix 33. Ancova of stand biomass components. June 1978. (tonnes ha^{-1}).

continued . . .

SOURCE	df	SS	MS	F	P
Blocks	2	0.006	0.003	0.575	ns
Treatments	(3)	1.957	0.652	124.132	***
Fert	1	0.460	0.460	87.518	***
Thin	1	1.364	1.364	259.558	***
F x T	1	0.133	0.133	25.235	***
(Co-variate)	1				
Error	5	0.026	0.005		
Total	10	1.989			

Treatment Means	C	F	T	F + T
	3.90	4.11	4.39	5.03
P = 0.05				
P = 0.01	- - - -	- - - -		

Branch wood weight

SOURCE	df	SS	MS	F	P
Blocks	2	0.051	0.025	0.446	ns
Treatments	(3)	8.744	2.915	51.056	***
Fert	1	1.922	1.922	33.667	***
Thin	1	6.511	6.511	114.053	***
F x T	1	0.312	0.312	5.467	*
(Co-variate)	1				
Error	5	0.285	0.057		
Total	10	9.080			

Treatment Means	C	F	T	F + T
	10.50	11.03	11.71	12.91
P = 0.05				
P = 0.01	- - - -	- - - -		
		- - - -	- - - -	

Stem weight

Appendix 33. Ancova of stand biomass components.
June 1978. (tonnes ha^{-1}).

Source	df	SS	MS	F	P
Blocks	2	0.028	0.014	0.481	ns
Treatments	(3)				
Fert.	1	2.900	2.900	98.575	***
Thin.	1	4.267	4.267	145.072	***
F x T	1	0.023	0.023	0.773	ns
(Covariate)	1				
Error	5	0.147	0.029		
Total	10	7.355			

Treatment Means	C	F	T	F + T
	5.15	6.11	6.30	7.46
P = 0.05		------		
P = 0.01		------		

Needle weight

Source	df	SS	MS	F	P
Blocks	2	0.080	0.430	0.521	ns
Treatments	(3)				
Fert.	1	89.254	89.254	108.173	***
Thin.	1	129.743	129.743	157.243	***
F x T	1	0.910	0.910	1.103	ns
(Covariate)	1				
Error	5	4.126	0.825		
Total	10	224.893			

Treatment Means	C	F	T	F + T
	27.24	32.56	33.57	40.02
P = 0.05		------		
P = 0.01		------		

Total weight

Appendix 34. Ancova of stand biomass components.
June 1979. (tonnes ha^{-1}).

continued . . .

Source	df	SS.	MS	F	P
Blocks	2	0.526	0.263	2.810	ns
Treatments	(3)				
Fert.	1	8.223	8.223	87.803	***
Thin.	1	5.959	5.959	63.621	***
F x T	1	0.946	0.946	10.100	*
(Covariate)	1				
Error	5	0.468	0.094		
Total	10	15.122			

Treatment Means	C	T	F	F + T
	5.75	6.65	6.96	9.02
P = 0.05		– – –	– – –	
P = 0.01	– – – –	– – – – –	– – –	

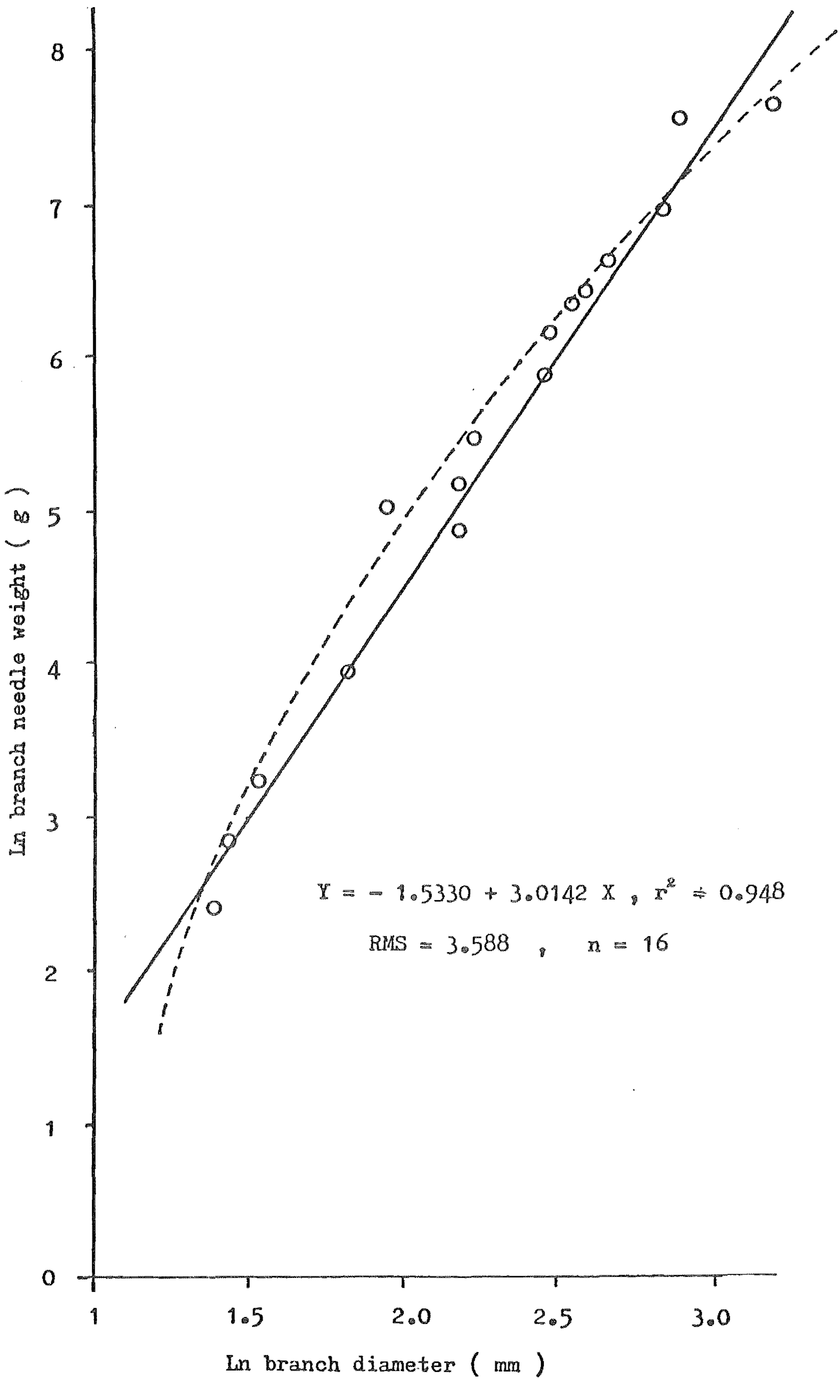
Branch wood weight

Source	df	SS	MS	F	P
Blocks	2	0.290	0.145	0.554	ns
Treatments	(3)				
Fert.	1	30.214	30.214	115.422	***
Thin.	1	43.539	43.539	166.325	***
F x T	1	0.360	0.360	1.376	ns
(Covariate)	1				
Error	5	1.309	0.262		
Total	10	75.711			

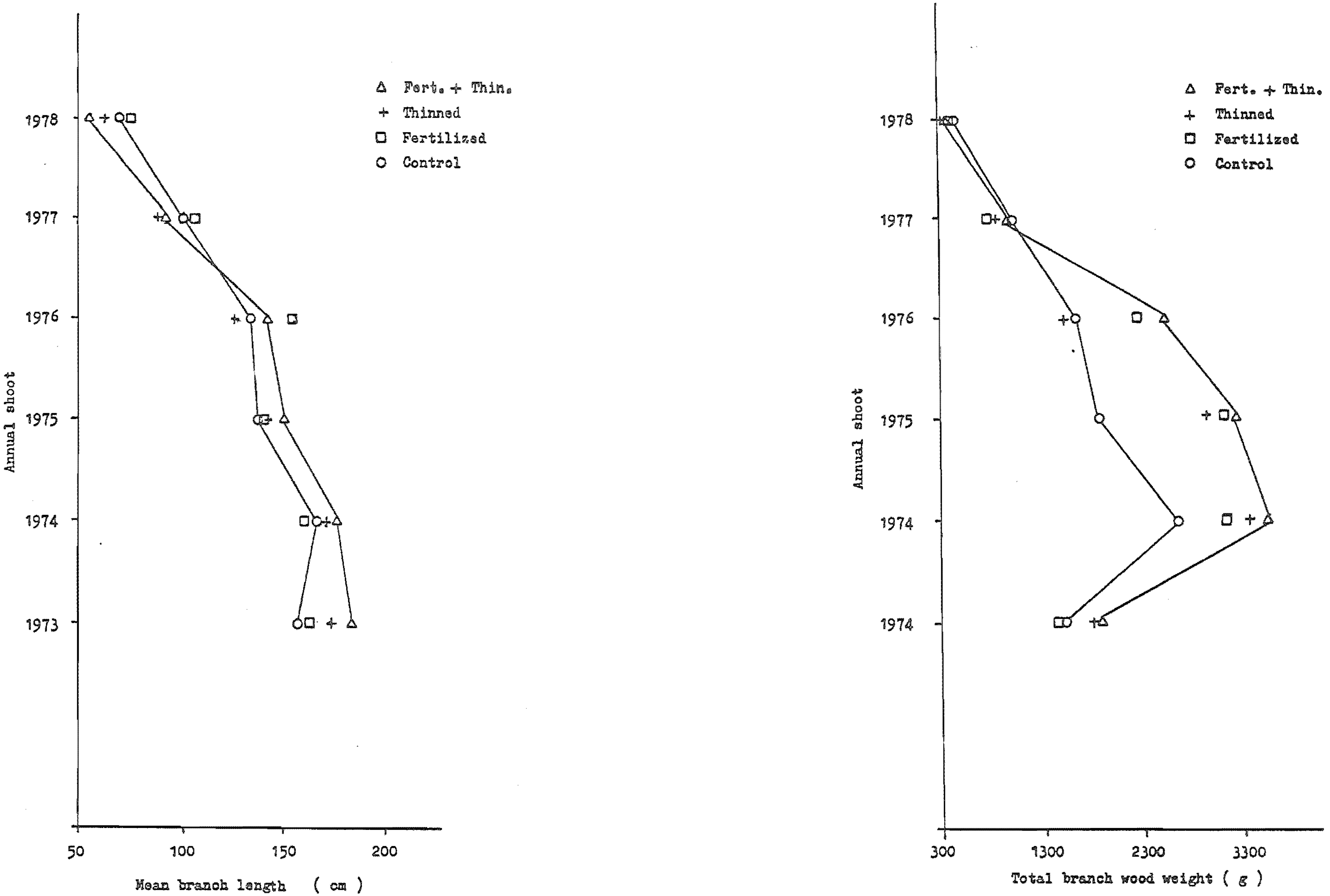
Treatment Means	C	F	T	F + T
	15.31	18.38	18.95	22.73
P = 0.05		– – –	– –	
P = 0.01		– – –	– –	

Stem weight

Appendix 34. Ancova of stand biomass components.
June 1979. (tonnes ha^{-1})

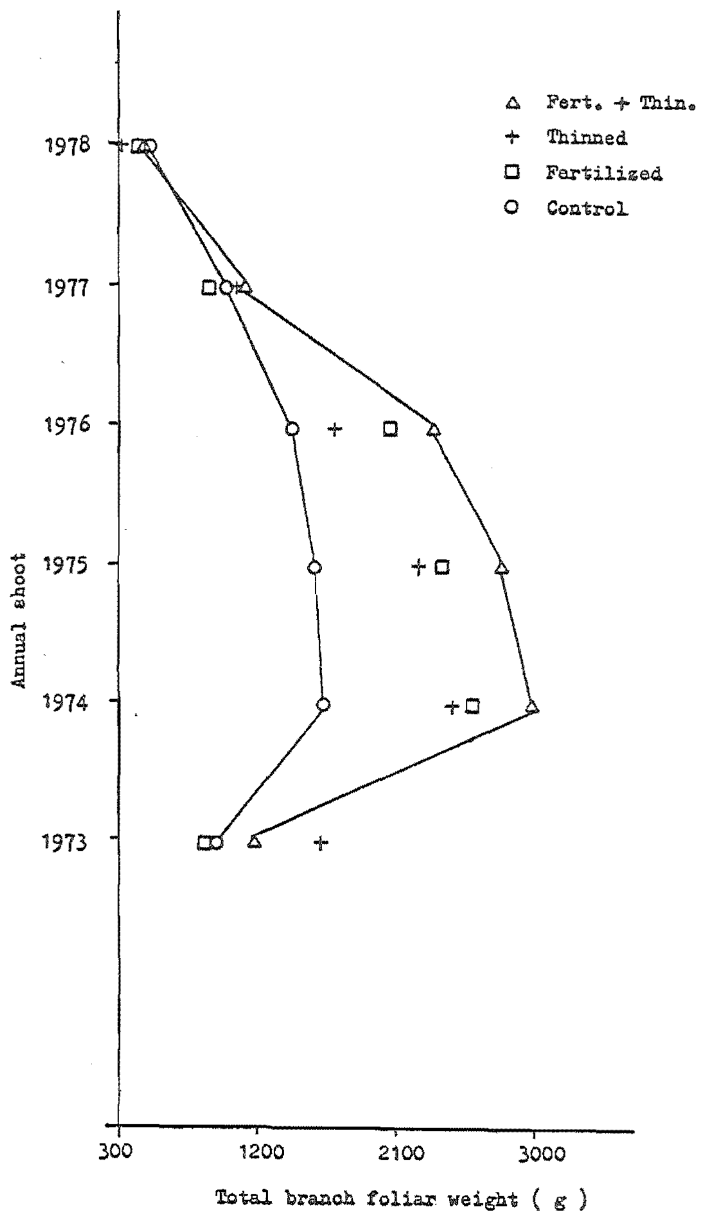


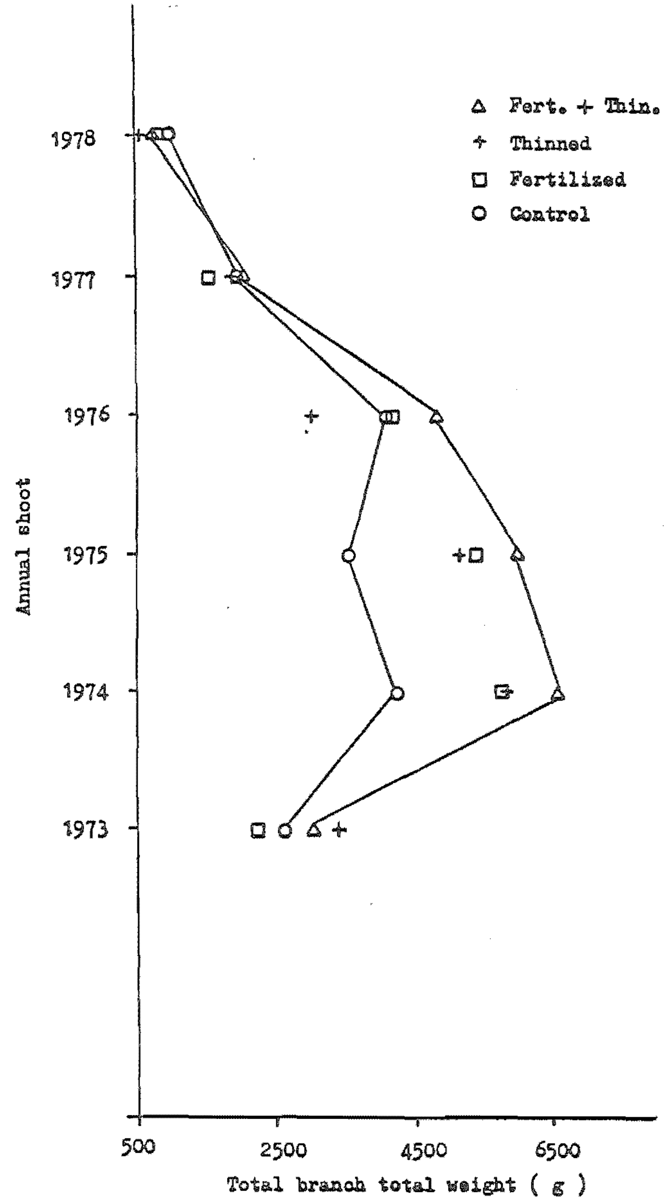
Appendix 35. Relationship of ln foliar weight to ln branch diameter. Each point the mean of a 5% relative height zone of 12 trees.



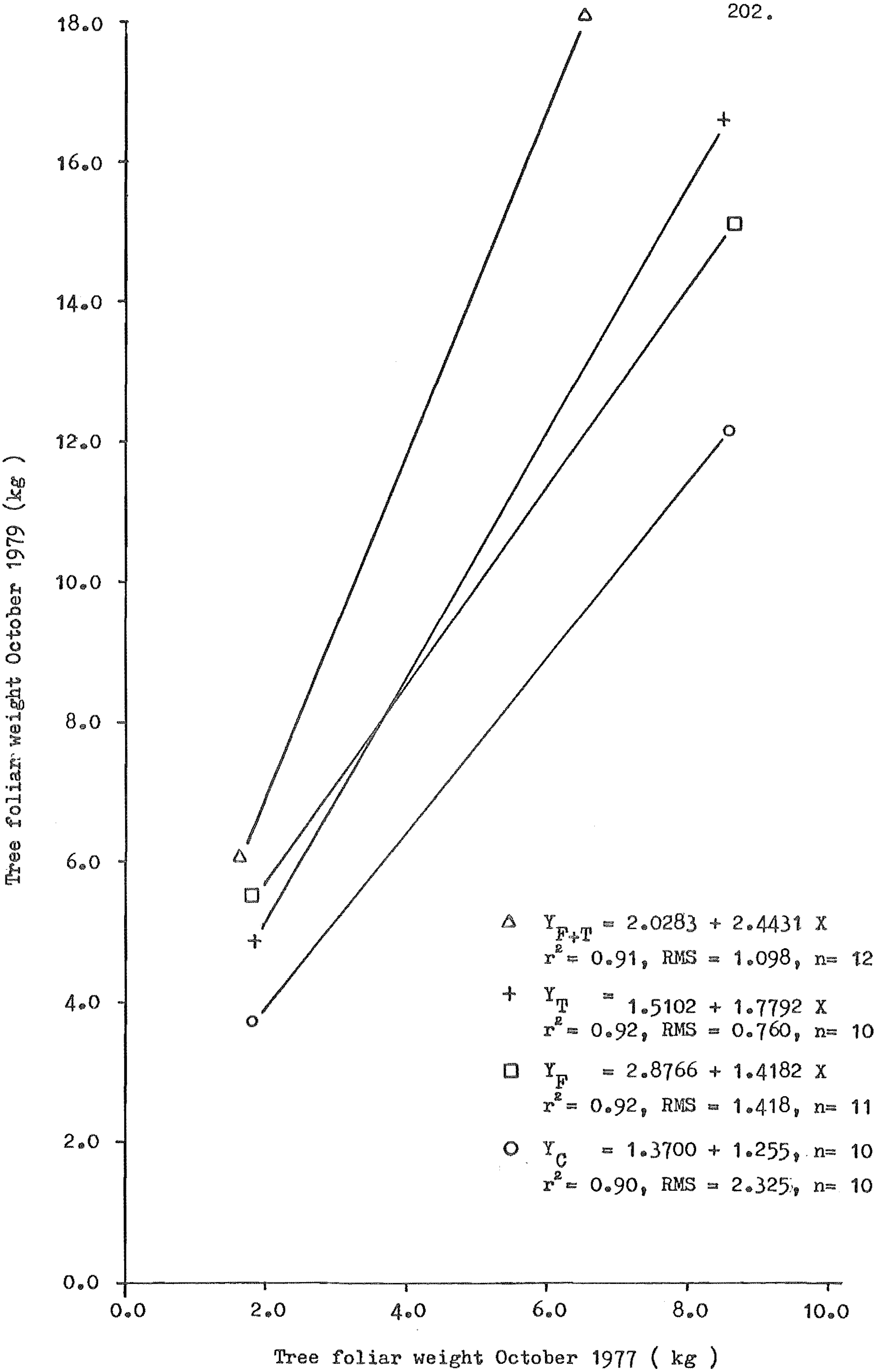
Appendix 36. Branch length and wood weight predicted after two years. October 1979.

continued . . .





Appendix 36. Branch foliar and total weight predicted after two years. October 1979.



Appendix 37. Tree foliar weight (1979) regressed upon tree foliar weight (1977).

Source	df	SS	MS	F	P
Blocks	2	4.681	2.341	2.40	ns
Treatments	(3)				
Fert.	1	69.345	69.345	71.17	***
Thin.	1	75.216	75.216	77.19	***
F x T	1	6.335	6.335	6.50	*
(Covariate	2)				
Error	35	34.102	0.974		
Total	40	201.151			

Treatment means	C	F	T	F+T
	6.98	8.76	8.87	12.22
P = 0.05		— — — — — —		
P = 0.01		— — — — — —		

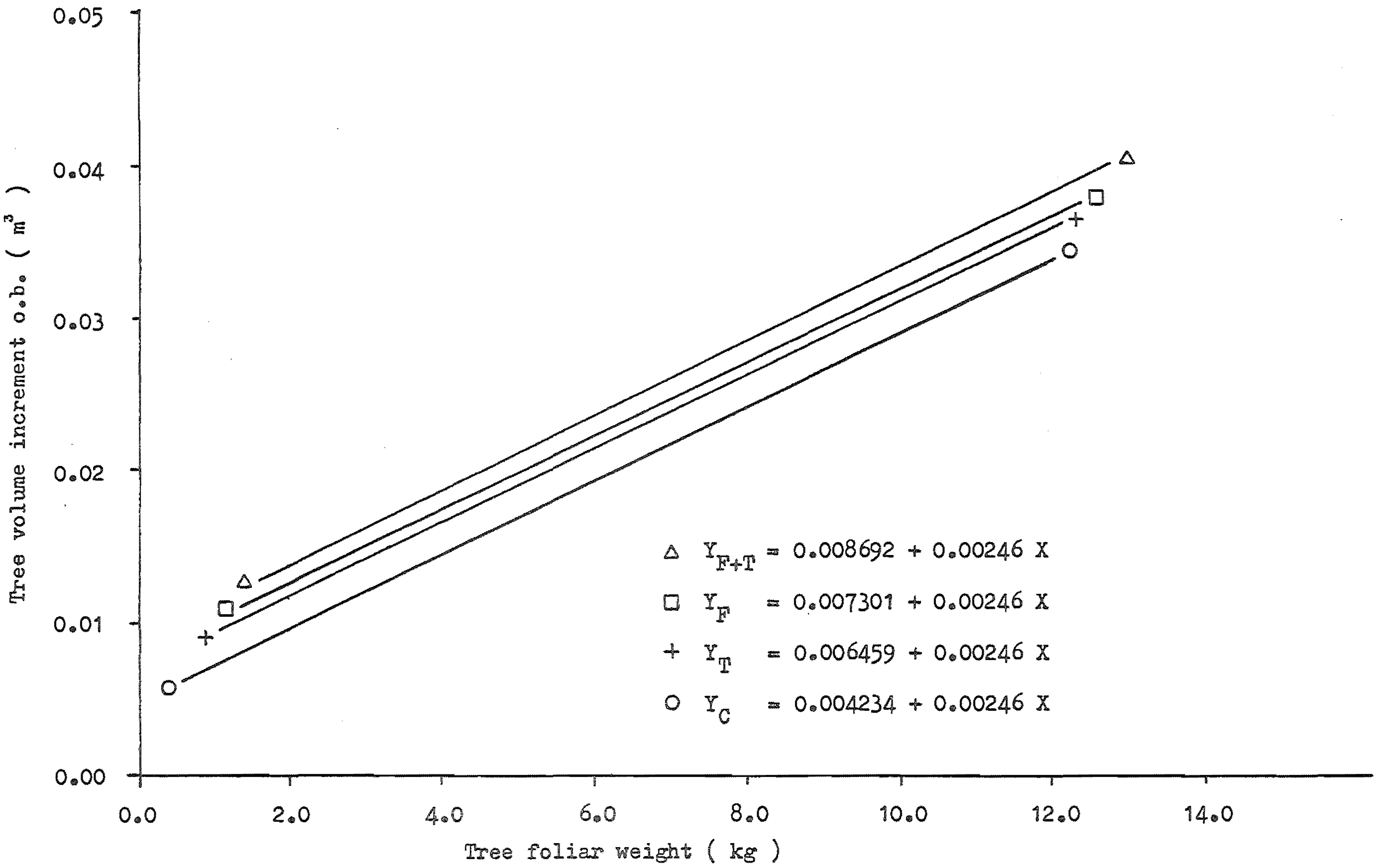
Appendix 38. Anova of adjusted treatment mean tree foliar weight (kg). October 1979.

	df	Σx^2	Σxy^2	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	9	1513740.0	346066.0	86264.0	0.229	8	7147.589	893.449
Fert	10	1105150.2	277874.8	84124.2	0.251	9	14256.380	1584.042
Thin	9	340093.6	92863.6	29855.6	0.273	8	4498.909	562.364
F + T	11	702898.3	182549.8	63400.3	0.260	10	15990.243	1599.024
						35	41893.121	1196.946
Pooled	39	3661882.0	899354.2	263644.0	0.246	38	42763.645	1125.359
		Difference between slopes				3	870.524	290.175
P + B	42	3918750.5	978627.2	312495.7	0.250	41	68067.698	1660.188
		Difference between levels				3	25304.053	8435.684

Comparison of slopes: F = 290.175 / 1196.946 = 0.242 ns

Comparison of levels: F = 8435.684 / 1125.359 = 7.495 ***

Appendix 39. Ancova upon tree volume increment ($m^3 \times 10^{-4}$) regressed upon tree foliar weight (kg $\times 10^{-2}$).



Appendix 40. Tree volume increment (1978) regressed upon tree foliar weight (1978).

	df	Σx^2	Σxy^2	Σy^2	Reg'n Coef.	Deviation from Reg'n df	SS	MS
Cont	9	1513740.0	346066.0	86264.0	0.229	8	7147.589	893.449
F + T	11	702898.3	182549.8	63400.3	0.260	10	15990.243	1599.024
						18	23137.832	1285.435
Pooled	20	2216638.3	528615.8	149664.3	0.238	19	23601.907	1242.206
		Difference between slopes				1	464.075	464.075
P + B	21	2231588.6	550159.9	183062.8	0.247	20	47430.251	2371.513
		Between adjusted means				1	23828.344	23828.344

Comparison of slopes: F = 464.075 / 1285.435 = 0.361 ns

Comparison of levels: F = 23828.344 / 1242.206 = 19.182 ***

Appendix 41. Ancova upon tree volume increment ($m^3 \times 10^{-4}$) regressed upon tree foliar weight ($kg \times 10^{-2}$). Control and Fert. + Thin. treatments.